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Artificial Drying of Cambodian Fish[1]

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ABSTRACT

Through the direction of the Colombo plan, a request was received to study the possibility of artificial drying for Cambodian fish and also to design a dryer which could be used economically under the adverse atmospheric conditions prevailing in tropical countries. Various samples were sent from Cambodia to this Station for tests. It was found possible to dry this fish artificially at a good drying rate without any difficulty. A drying temperature of 110°F (43°C) can be used without any injury to the product. According to atmospheric data supplied by the weather bureau, the dew point of the air in Cambodia is always between 72.5 and 77°F (22 and 25°C), so that artificial drying is possible there without costly dehumidifying apparatus. As a result of these important findings an experimental dryer of 2-ton (1800-kg) capacity was designed. The dryer is very simple and economical and will be used in Cambodia for judging, according to local market requirements, the quality obtained; also for determining the efficiency of a possible future big unit which will include six sections similar to the 2-ton trial unit.

INTRODUCTION

THE FRESHWATER FISHERIES of Cambodia are very important for the local economy as well as for the nutrition of the local population. Various species are encountered including oily and non-oily fish. Some are very small (3 to 4 inches or 7.5 to 10 cm long), others are about the size of a medium Canadian codfish. The fish are caught in huge quantities during very short time intervals so that the available supply often exceeds the facilities for disposal by the fresh fish trade. Moreover, the captures are often made in locations far away from the centres of the fresh fish trade, or during a season in which transportation is handicapped. Therefore a substantial part of the catches has to be used for the dry fish industry.

CAMBODIAN PROCESSING METHODS

Heads and entrails are removed. Then the fish are split, washed, salted and finally dried in the sun on bamboo flakes. Some species are soaked during 16 hours in vats before being split and salted. This operation expands the tissues and allows a certain degree of fermentation, which is considered a desirable feature on account of flavour developed thereby.

When the vicinity of the fishing grounds enjoys a fair amount of sunshine, a good breeze and a low relative humidity, a stable dried product is obtained within 48 hours. The product is then shipped to the Central Co-operative

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warehouse at Russey Keo near Phnompenh. At these headquarters, a final drying operation, requiring only 6 hours if the weather is suitable, takes place. The product thus obtained is exported.

Under ideal conditions, this reasonably efficient procedure is economical, but only because the cost of labour is very low. However, ideal conditions do not prevail all year round because the rainy season, during which 25 to 30% of the catches are made, lasts about 4 months. In fact, during the rainy season it takes about 3 days at the central warehouse to finish drying the fish and considerable losses are encountered by the fishermen. The greatest trouble arises from a reddening which develops on salted fish when exposed to moisture and rain. The fish so attacked cannot be exported and has to be sold on the local markets for what it will fetch.

It has been suggested that these various difficulties could be overcome by a suitable artificial drying procedure. Through appropriate channels, the Colombo Plan was approached for help by the Co-operative of Cambodia in the solution of the drying problems. The request was passed on to the Fisheries Research Board of Canada, which assigned this Technological Station to study experimentally the feasibility of artificial drying under the adverse conditions that sometimes prevail, as explained above, and also to design an apparatus for that purpose.

General Considerations

The first step consisted of a series of conferences with Mr Louis Bérubé, officer of the Colombo Plan, who had spent several months in Cambodia. He was able to supply much useful information concerning the difficulties encountered with the various types of fish, methods of handling, and atmospheric conditions prevailing there. The details supplied offered promise that the fish could be dried successfully by artificial means. But the difficulty was to develop a procedure and to design an apparatus which would be suited to such a cheap product under tropical conditions. Two dryers have already been installed in the East; one in Hong Kong and the other one in Colombo, Ceylon. Both dryers, however, are equipped with dehumidifying equipment and the drying operation is conducted at about the same temperature (80°F or 27°C) being used here in Canada for the preparation of various types of salt fish.

Sun drying requires only labour, which is very cheap in tropical countries, so that the use of a dehumidifying system in conjunction with an artificial dryer might not prove competitive. The removal of water from the air is usually accomplished either by refrigeration or by chemical absorption. Both systems are costly to install and expensive to operate. Improvements in these respects are to be expected in the future; however, for the present our efforts have been directed at obtaining satisfactory results without the use of external dehumidifiers.

The amount of moisture that can be carried by a pound of air increases rapidly with rise in temperature as shown in humidity charts. Therefore, for any given product, the highest temperature possible should be used because of faster drying and smaller requirements for ventilation. The limiting conditions

are those principally set by the properties of the product itself. From atmospheric data supplied by the Weather Bureau of Cambodia, it seemed likely that it would be possible to employ air temperatures considerably higher than those normally used for the artificial drying of Atlantic salt codfish in Canada. Therefore the prospects appeared hopeful for a satisfactory drying rate even in the absence of a dehumidifying system. This working hypothesis was based on the theoretical considerations outlined hereunder.

With wet fish the drying rate depends mainly on the difference in temperature between the air stream and the wet surface of the fish, which assumes a temperature corresponding to the wet-bulb temperature of the air. When external dehumidification is applied, the absolute humidity is decreased and consequently the wet-bulb temperature is reduced. This increases the difference between the dry- and wet-bulb temperatures and the drying rate. However, we know from psychrometry that the difference between the dry- and wet-bulb temperatures will also increase with an increase in the temperature of the air, even though the absolute humidity remains constant. A thermocouple system of control, based on the latter principle, yielded interesting results with light and heavy salted codfish (Legendre, 1958). The method uses a thermocouple, inserted in the flesh near the surface, to regulate temperature of the air circulating in the dryer. There is no danger of overheating the product and the air is always at the highest possible temperature. Dehumidification is required only when it is known that the highest feasible dry-bulb temperature of the air does not produce a satisfactory drying rate.

Information concerning drying of Cambodian fish is scarce. Therefore it was decided to run a series of drying experiments here at Grande-Rivière, before making any attempt to design a dryer.

The Colombo Plan officers organized and executed the dispatch of semi-dried salt fish from Cambodia to Grande-Rivière.

The purpose of these experiments was to ascertain the highest temperature that may safely be employed and to determine the drying rate at this temperature. Having secured this information, the next step would consist of designing an appropriate apparatus, suitable for the preparation of dried Cambodian salt fish under the unfavourable atmospheric conditions prevailing in that country during the rainy season.

DRYING POSSIBILITIES OF CAMBODIAN FISH

General Procedure

The fish sent from Cambodia by air arrived here after 2 weeks. They had been semi-dried and corresponded to the product which usually is sent to the central plant in Cambodia. The 2-week trip did not seem to affect the quality of the product. There was some odour of rancidity but apparently this is not always regarded as detrimental in some Cambodian-processed fish products.

The air shipments consisted of representatives of several species (Table I). Each was analyzed before and after drying. The drying experiments were performed with the already available experimental salt fish dryer designed at this Station. This dryer is of the batch compartment type and is equipped with temperature and relative humidity controllers so that any temperature between 60 and 150°F (15.6 and 66°C) and any relative humidity between 30 and 90% can be maintained.

The air circulating over the fish inside the dryer was maintained at a constant velocity of about 350 feet (107 m) per minute. During the drying experiments, samples were taken at intervals and weighed. The data recorded here represent the loss of moisture by the fish and the values refer to "dry basis" (pounds of moisture lost per 100 lb of bone-dry material). This value, represented by the symbol L and the drying rate $\triangle L/\triangle \theta$ (pounds of moisture lost per hour per 100 lb of dry material where θ = time in hours), is obtained directly by a simple graphical differentiation of the moisture-loss curve. Moisture determinations were made by the oven method using a temperature of 105°F (40.5°C). Salt content analyses were made by the silver nitrate method (Dyer, 1943). The fat content was determined by Soxhlet extractions with ether.

Drying Experiments

The results of the first series of experiments indicated clearly that it is possible to dry fish artificially. No difficulties were experienced. The analytical figures, shown in Table I, were obtained before and after drying at 80, 90 and 100°F and at relative humidities of 40, 50 and 60%. Equally good products were obtained in all experiments. As expected, the best drying rates were observed at high temperatures and low relative humidities. The drying rate is higher than that of light salted codfish. This is probably due to the fact that the Cambodian fish is smaller and thinner, and also because it is cut and split in such a way as to increase the exposed surface or to decrease the actual thickness

Table I. Results of analysis made on the first shipment of Cambodian fish.

	Name of fish					
	Trey Chhkok		Trey Chdor	Trey Pra	Trey Linh	Chhkok Tituy and Chhpin
	Large	Small				
	%	%	%	%	%	%
Fat content (dry basis)	1.25	16.1	5.7	12.7	29.5	22.3
Salt content (dry basis)	33.0	21.0	28.6	29.7	17.9	14.7
Moisture content (wet basis)	50.0	40.0	40.0	42.0	31.4	39.2
Moisture content (wet basis) after 24-hour drying period at:						
Temp. 80°F (26.7°C), Relative humidity 60%	40.5	24.6	32.1	34.3	20.5	28.6
Temp. 90°F (32.2°C), Relative humidity 50%	36.3	18.9	29.3	32.1	18.1	27.7
Temp. 100°F (37.8°C), Relative humidity 40%	32.6	13.6	24.1	21.2	13.5	17.7

of the fish. The fat content of most of these fish is much higher than that of codfish. Only two products, namely Trey Chdor and large Trey Chhkok, were found to have a low fat content (Table I). According to their salt content the samples may be classified as light and medium salted fish.

As the initial moisture content of the batches of fish used in the first experiments was quite low it was considered desirable to repeat the experiments with other batches of higher moisture content.

The initial water content of the second batch of Trey Chdor and Trey Linh was about 10% higher than in the first batch (Table II). Correspondingly the quality was not as high on arrival. The product was softer and the smell of rancidity was stronger than with the first batch. It was found also that the fat content of the Trey Chhkok samples (large and small) was much higher than in the first shipment. In spite of these detrimental factors good results were

TABLE II. Results of analysis made on the second shipment of Cambodian fish.

	Name of fish			
	Trey Chhkok		Trey Chdor	Trey Linh
	Large	Small		
	%	%	%	%
Fat content (dry basis)	14.2	33.5	2.5	27.4
Salt content (dry basis)	25.7	20.1	24.5	28.8
Moisture content (wet basis)	50.4	40.0	56.5	41.8
Moisture content (wet basis) after 30-hour drying period at:				
Temp. 80°F (26.7°C), Relative humidity 30%	35.5	20.0	35.0	...
Temp. 80°F (26.7°C) Relative humidity 50%	36.0	23.9	40.6	...
Temp. 100°F (37.8°C) Relative humidity 50%	37.5	20.6	39.2	...
Temp. 110°F (43.3°C) Relative humidity 50%	...	23.8	35.8	11.0

obtained with all samples, even when drying temperatures as high as 110°F (43°C) were used.

In judging the quality of the Cambodian products, the author applied his experience with Canadian salt cod and considered the general appearance only. Since this judgment is not necessarily compatible with the requirements and food habits of Cambodia, confirmation of his views was requested from Mr Bérubé and visitors from Indonesia. According to these referees, the quality of the artificially dried products was decidedly satisfactory and comparable to a good average quality product marketed in Cambodia. If was therefore concluded that a temperature of 110°F is not harmful for these products and can safely be used to dry Cambodian fish artificially. If we consider that an increase in

temperature results in a decrease in relative humidity and consequently increases the drying potential of the air, it is warrantably concluded that, taking into account the atmospheric conditions in Cambodia, a temperature of 110°F will result in a relative humidity low enough to permit drying without any special dehumidifying system.

Variations of Drying Rate

From the weighings made during the drying experiments the moisture-loss curves were constructed. From these the drying-rate curves were obtained by graphical differentiation. Figure 1 shows the moisture-loss and drying-rate

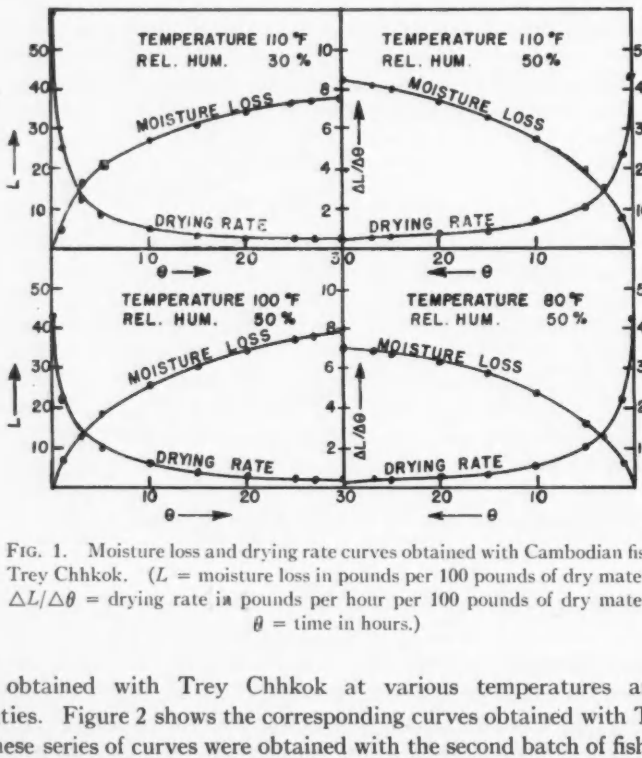

Fig. 1. Moisture loss and drying rate curves obtained with Cambodian fish—Trey Chhkok. (L = moisture loss in pounds per 100 pounds of dry material; $\Delta L/\Delta\theta$ = drying rate in pounds per hour per 100 pounds of dry material; θ = time in hours.)

curves obtained with Trey Chhkok at various temperatures and relative humidities. Figure 2 shows the corresponding curves obtained with Trey Chdor. Both these series of curves were obtained with the second batch of fish. The corresponding data are shown in Table III and indicate that the drying rate is much higher with Trey Chdor than with Trey Chhkok. However, the variations of the drying rate, which are caused by changes in temperature or relative humidity, are about the same in both cases. As expected, the drying rate increases with temperature and the increase is encountered during the whole drying operation. Therefore, the overall moisture loss is much higher at a

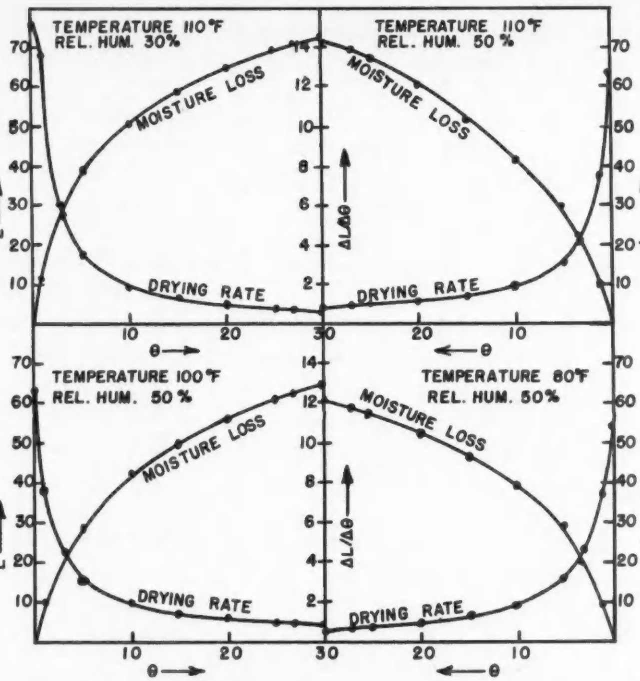

FIG. 2. Moisture loss and drying rate curves obtained with Cambodian fish—Trey Chdor. (L = moisture loss in pounds per 100 pounds of dry material; $\Delta L/\Delta\theta$ = drying rate in pounds per hour per 100 pounds of dry material; θ = time in hours.)

high temperature than at a lower temperature. From these experiments 110°F (43°C) seems the best temperature to be used for the artificial drying of Cambodian fish. Higher temperatures could not be studied with the limited amount of material on hand but it is not impossible that they could be used.

The relative humidity influences the drying rate mainly during the first part of the drying operation, when the surface is wet or partly wet. For example, with Trey Chhkok the drying rate during the first two drying hours is higher at 30% relative humidity than at 50%. Near the end of the operation however, when case-hardening occurs, the picture is reversed. The overall result is that the total moisture loss is slightly higher at 50% than at 30%. A similar effect was encountered with Trey Chdor, but in that case the total moisture loss was about identical for both relative humidities. To avoid case-hardening it would be necessary to use a low relative humidity at the beginning and to increase it for the last part of the operation. This procedure was successfully applied to Gaspé-cure fish (Legendre, 1955). Another way could be to use thermocouple

TABLE III. Moisture loss and drying rate obtained with two species of Cambodian fish.

Sample:	Trey Chhkok								Trey Chdor							
Temperature:	110°F				100°F		80°F		110°F				100°F		80°F	
Rel. hum.:	30%		50%		50%		50%		30%		50%		50%		50%	
Drying time, hours	L	$\Delta L/\Delta\theta$	L	$\Delta L/\Delta\theta$	L	$\Delta L/\Delta\theta$	L	$\Delta L/\Delta\theta$	L	$\Delta L/\Delta\theta$	L	$\Delta L/\Delta\theta$	L	$\Delta L/\Delta\theta$	L	$\Delta L/\Delta\theta$
0	0.0	12.0	0.0	8.8	0.0	8.5	0.0	8.0	0.0	15	0.0	16	0.0	12.7	0.0	11.0
1	9.0	5.1	7.5	4.8	7.0	4.5	6.0	4.4	12.0	13.6	11.0	7.7	10.0	7.5	9.0	7.3
3	16.5	2.7	14.5	2.8	13.5	2.7	12.5	2.6	30.0	5.3	22.5	4.2	21.5	4.6	20.0	4.5
5	21.0	1.7	19.7	2.1	18.0	2.0	16.8	1.9	39.5	3.3	29.5	2.9	29.0	3.0	28.0	3.1
10	27.0	0.95	27.5	1.3	26.0	1.2	24.2	1.1	51.0	1.8	42.4	2.2	40.8	1.9	39.5	1.8
15	31.0	0.66	33.2	0.93	31.0	0.85	28.8	0.75	58.5	1.4	52.0	1.7	49.0	1.4	47.0	1.3
20	34.0	0.52	37.2	0.70	34.8	0.60	32.0	0.48	64.8	1.1	60.0	1.5	55.0	1.15	52.5	1.0
25	36.0	0.40	40.2	0.53	37.1	0.41	33.8	0.27	69.6	0.93	67.0	1.3	60.5	0.95	57.0	0.79
27	37.0	0.37	41.2	0.43	38.0	0.35	34.2	0.20	71.5	0.81	69.5	1.2	62.5	0.87	58.5	0.70
30	38.0	0.31	42.2	0.37	38.8	0.30	34.8	0.13	74.0	0.70	73.0	1.1	65.0	0.80	60.5	0.60

control (Legendre, 1958). If the relative humidity is to be kept constant for the complete operation from beginning to end, it should be regulated to around 50 to 55%.

In all experiments an air velocity of 350 feet (107 m) per minute was used It is well known that high air velocities increase the amount of heat transferred between the air and the product, as compared with lower air velocities, so that the drying rate increases. Besides, high air velocities usually result in more uniform conditions inside the dryer. However, the horsepower requirements increase very rapidly with increasing air velocities and it is generally considered more economical to use an air velocity ranging from 250 to 500 feet (76 to 152 m) per minute, which results in a satisfactory drying rate, adequate air distribution and heat transfer.

Atmospheric Conditions

Readings of temperatures and relative humidities for different periods of the year 1954 were obtained from Cambodia and the averages of these readings are shown in Table IV. It may be seen that the mean dew points fluctuate between 72.5 and 77°F (22.5 and 25°C) during the dry and the humid months. This is explained by the fact that an increase in relative humidity corresponds to a certain decrease in temperature.

Table IV. Atmospheric conditions in Cambodia, 1954.

	Dry months		Humid months	
	March	April	August	September
Mean temperature, °F (°C)	85.3(29.5)	96.6(35.9)	83.1(28.4)	81.3(27.4)
Mean relative humidity, %	64.9	72.1	81.1	82.7
Mean dew point, °F (°C)	72.5(22.5)	77.0(25.0)	77.0(25.0)	75.5(24.2)

For practical purposes calculations were based on a dew point of 77°F (25°C). Assuming this value and 110°F (43°C) as the temperature of the air which will be used to circulate over the fish, it may be found from psychrometric charts that the resulting relative humidity will be about 36%. This is certainly low enough to permit good drying without additional dehumidification.

ARTIFICIAL DRYER FOR CAMBODIA

Since the results of the experiments reported above justify the establishment of an industrial dryer in Cambodia, it was decided to recommend one of 2-ton (1800-kg) capacity for the following reasons.

A unit of this size would be large enough for the Cambodian technicians to experiment on the preparation of batches on an industrial scale. Batches of 2 tons would also be representative enough for judging the quality obtained

according to local market requirements. Besides, types of fish other than those investigated and described in this paper could be dried experimentally, and finally this 2-ton dryer is designed in such a way that four or six similar sections could be added whenever necessary.

General Arrangement

Figure 3 shows a sketch of the experimental dryer for Cambodia. The dryer is very simple and consists essentially of a drying tunnel, a fan and a steam heater. It may be noted that no provision has been made for recirculating the air. In temperate regions recirculation is required on account of large variations in the dew points of the atmosphere. In Cambodia, however, the dew point does not vary extensively and for practical purposes the inlet conditions can be assumed to be constant if the temperature is regulated. Since the dew point is around 77°F (25°C) the inlet air is constantly moist and the outlet air after passing over the fish has therefore a higher moisture content. Recirculation

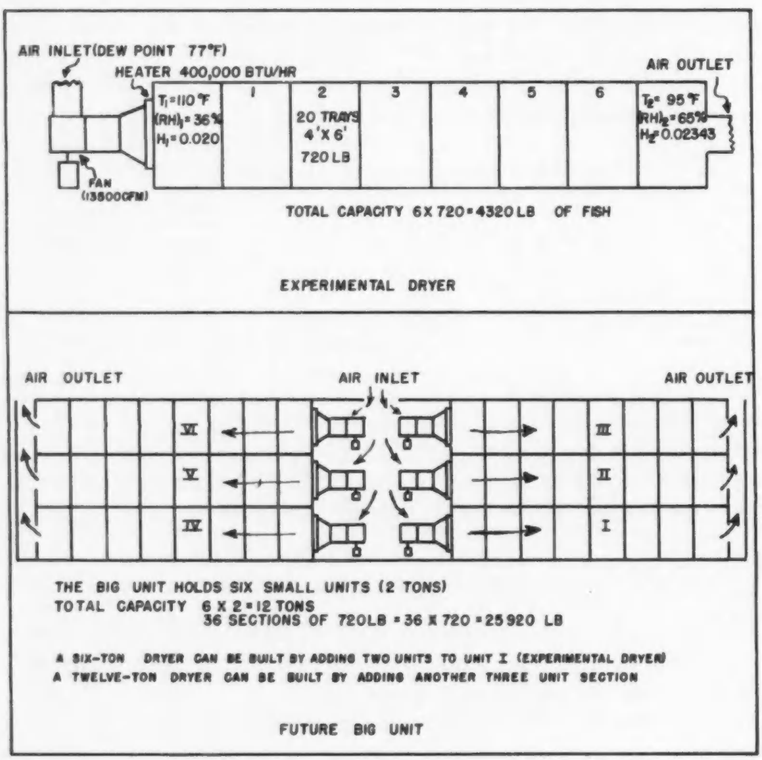

Fig. 3. Sketch of dryer for Cambodian fish.

would thus reduce the efficiency of the dryer. The only control equipment is a temperature controller which is set at 110°F (43°C) and which should be located at the beginning of the drying tunnel. The mean relative humidity of the air in the dryer depends on the inlet conditions and on the amount of moisture removed from the fish. It will therefore vary with the overall drying rate. In a following section of this paper detailed instructions are given for a procedure which will give a more uniform overall drying rate and consequently a more constant relative humidity.

NUMBER OF TRAYS

A dryer of a 2-ton capacity suitably consists of six sections, holding about 700 lb each. It was found experimentally that 1.5 lb of fish required about 1 square foot on the trays. The usual size of the trays being 4 by 6 feet, each will then hold about $4 \times 6 \times 1.5 = 36$ lb of fish. Using 20 trays per section, or $20 \times 36 = 720$ lb of fish, this will give a total capacity of $6 \times 720 = 4320$ lb of fish in the dryer. The distance measured from centre to centre of the different trays should be 4 inches; therefore the inside height of the dryer will be $(21 \times 4)/12 = 7$ feet.

INLET AND OUTLET CONDITIONS

It was explained above that the dew point in Cambodia may be assumed as 77°F and that an inlet temperature T_1 of 110°F will result in a relative humidity $(RH)_1$ of 36%. Psychrometric charts show that under these conditions the absolute humidity of the air H_1 is 0.02000 lb of water per pound of dry air. It was shown also that the relative humidity of the air will vary with the overall drying rate. Therefore, the best design for a dryer should combine the highest possible relative humidity with the maximum drying rate. It is however not practical to use relative humidities higher than 65% because above this percentage the drying rate is reduced considerably. Psychrometric data show that a Cambodian dryer designed to work at a relative humidity $(RH)_2$ of 65% at the outlet will have an outlet temperature T_2 of 95°F and that its absolute humidity H_2 will be 0.02343 lb of water per pound of dry air. This is valid under the assumption that all the sensible heat given by the air is used to evaporate water from the fish inside the dryer. Consequently, the weight of water gained by each pound of dry air is equal to:

$$H_2 - H_1 = 0.02343 - 0.02000 = 0.00343 \text{ lb water/lb dry air.}$$

AIR REQUIREMENTS

The highest drying rate equal to 10 lb of water/hour/100 lb of dry material is encountered at the beginning of the drying operation when the moisture content of fish (Trey Chdor) is around 56.5% (Table II). Since the total capacity

of the dryer is equal to 4320 lb the overall weight of moisture taken from the fish by the air will be:

$$\frac{4320 \times 0.435 \times 10}{100} = 188 \text{ lb/hr.}$$

It was found above that each pound of air will gain 0.00343 lb of water. The air required is then equal to:

$$\frac{188}{0.00343} = 54800 \text{ lb/hr.}$$

The mean specific volume of the air inside the dryer (100°F and 50% R.H.) is found to be 14.6 cu ft/lb. Therefore, the volume of air circulating over the fish will be:

$$\frac{54800 \times 14.6}{60} = 13300 \text{ cu ft/min.}$$

For a free area of about $6 \times [7 - (20 \times 0.1)] = 6 \times 5 = 30$ sq ft the velocity of the air in the dryer will be:

$$\frac{13300}{30} = 444 \ (= \text{approximately } 450) \text{ ft/min}$$

The mean specific volume of the ambient air in Cambodia (dew point = 77°F as assumed before) is found to be 14.26 cu ft/lb. Therefore, the required volume of air entering the dryer will be:

$$\frac{54800 \times 14.26}{60} = 13020 \ (= \text{approximately } 13000) \text{ cu ft/min.}$$

HEAT REQUIREMENTS

Before entering the dryer, the air will have to be heated from about 80°F to 110°F (T_1). For an absolute H_1 of 0.020 the humid heat of the air is equal to:

$$0.24 + (0.446 \times 0.020) = 0.24 + 0.00892 = 0.249 \text{ BTU/lb/°F.}$$

Therefore the total heat requirement will be:

$$54800 \times 0.249 \times (110 - 80) = 410{,}000 \text{ BTU/hr.}$$

STEAM HEATER AND SUPPLY FAN

We know that 13000 cu ft/min of air at 80°F will have to be heated to 110°F by a steam coil. For this, a boiler having a capacity large enough to furnish about 410,000 BTU/hr to the steam heater is required. The pressure of the steam in the coil may be chosen to be around 5 lb. If we assume for the air circulating through the heater a face velocity of about 800 ft/min the required face area for the coil will be 16 sq ft. Therefore, a section of 4 × 4 ft may be chosen.

The resistance to air flow through the steam heater depends on various factors of which the face velocity of the air is certainly the most important. It

may be found from various tables of performance data that the air friction through the required coil will be around 1/6 or 0.167 in of water.

The resistance of air flow through the dryer may be found by assuming a clearance of 3 in between the dryer shelves and taking the formula for parallel plates for each of the 21 spaces.

Then: $p = \dfrac{12\mu LU}{ga^2}$ (Walker *et al.*, 1927)

where: p = pressure drop in lb/sq ft,

μ = absolute viscosity of air (at 80°F) in lb/sec/ft,
$= 0.018 \times 0.000672 = 12.1 \times 10^{-6}$,

L = frictional length in feet
$= 6 \times 4 = 24$ ft (6 sections, 4-ft trays),

U = air velocity inside the dryer in ft/sec
$= 450/60 = 7.5$,

$g = 32$ ft/sec/sec,

a = Clearance between shelves in feet
$= 3/12 = 0.25$,

$a^2 = (0.25)^2 = 0.0625$ sq ft.

$$\text{Then:}\quad p = \frac{12 \times 12.1 \times 10^{-6} \times 24 \times 7.5}{32 \times 0.0625}$$
$$= \frac{1.2 \times 1.21 \times 2.4 \times 7.5 \times 10^{-2}}{3.2 \times 6.25}$$
$$= \frac{0.013 \times 12 \times 21}{62.3} = 0.053 \text{ in of water.}$$

The resistance to air flow through the steam heater and through the dryer is $0.167 + 0.053 = 0.220$ in of water. There will be also some resistance at the outlet of the dryer and consequently it can be assumed that the total resistance against which the fan must operate is about 0.25 in of water. Therefore, the fan required must be able to handle 13000 cu ft of air per minute against a static pressure of 0.25 in of water. The horsepower output of the fan will then be:

$$\text{Air horsepower} = \frac{QP}{6356}$$

where: Q = volume of air circulated in cu ft/min
$= 13000$,

P = static pressure in inches of water
$= 0.25$.

$$\text{Then:}\quad \text{Air horsepower} = \frac{13000 \times 0.25}{6356} = 0.51.$$

The horsepower input will be:

$$\text{hp} = \frac{\text{horsepower output}}{\text{efficiency}}.$$

Assuming an efficiency of 60% for the fan, then:

$$\text{hp} = \frac{0.51 \times 100}{60} = 0.85;$$

consequently, a 1-hp motor will be required for the fan.

Operation of Dryer

The experimental dryer was designed in such a way that the cost of both operation and production is reduced to the minimum. The data shown in Fig. 3 are those obtained from the above calculations and apply to the highest drying rate which is encountered at the beginning of the drying procedure when a batch operation is being used. In that case the relative humidity at the end will never exceed 65% and will decrease when the drying rate is reduced. As shown in Fig. 1 and 2, the drying rate decreases very rapidly and after only 5 hours it is close to 3 lb water/hour/100 lb of dry material (Table III). At that stage the outlet conditions will be $T_2 = 105°\text{F}$ and $(RH)_2 = 44.5\%$. Near the end of the operation when the value of the rate is about 1.0, the outlet conditions will be $T_2 = 108°\text{F}$ and $(RH)_2 = 39\%$.

It is quite possible to construct other dryers which would have a better drying rate. However, for the design described here economy and ease of operation were the dominant considerations. These factors are certainly most important for this particular application. It is felt that the arrangement, if operated properly, will yield a product of satisfactory quality. As pointed out previously for the preparation of this and other types of dried fish the best possible drying rate is obtained when a low relative humidity is used for the first few hours (when the surface of the product is wet or partly wet) and a higher relative humidity for the later stages of the operation (when the surface is dry). With a simple batch operation as suggested here, the above cannot be applied. The relative humidity inside the dryer, which depends on the drying rate, will be high at the beginning and low at the end of the operation.

This complication can nevertheless be alleviated if the dryer is charged at regular intervals with smaller batches of one-quarter, one-third, or even one-half of its total capacity. That is to say, every time a quantity of green fish is charged, a similar quantity of dried fish is removed. Consequently the proportion of green, dried and semi-dried fish in the dryer will approach constancy throughout the process, variations of relative humidity will be reduced considerably, and the overall drying rate will be more uniform than in a true batch operation. To be more specific: the length of the dryer and the amount of newly charged fish determine the increase in relative humidity which in turn causes a reduction of the drying rate. But in the semi-continuous process outlined above the amount of newly charged fish is limited and therefore the increase in relative

humidity is minimized in comparison to a true batch operation. The presence of semi-dried fish is another favourable factor.

An additional improvement would be to use easily movable trucks carrying the trays and to feed the dryer at regular intervals as explained before. In that case the trucks carrying green fish should always enter the first section and be pushed gradually toward the last section inside the dryer, so that the properly dried fish is taken out from the last section. Such a procedure will result in a lower relative humidity for the green fish and in a higher relative humidity for the nearly dried product.

If the relative humidity of the air leaving the dryer falls too low, e.g. to between 40 and 50%, the use of a lower temperature for T_1 will correct the situation. For example a temperature of 100°F could be used during unusually dry months. On the other hand, if the relative humidity is too high some improvements are also possible. Several possibilities exist. If the relative humidity at the inlet $(RH)_1$ is high as well as at the outlet $(RH)_2$, the dew point of the air will be unusually high and the only way to correct the situation will be to try a higher temperature for T_1. Good results were obtained at 110°F. Higher temperatures could not be investigated with the amount of fish available, but it is possible that they could be used successfully. If, however $(RH)_2$ is high but $(RH)_1$ is low enough, then the drying rate of the fish inside the dryer will be much higher than expected. This is not likely to happen, unless the dryer is filled with very wet fish. In this case, one of the procedures outlined above for loading the dryer will result in considerable improvements.

Big Drying Unit

Figure 3 shows also the sketch of a proposed future big unit which comprises six small units similar to the one described above. The capacity of the big unit would be $6 \times 2 = 12$ tons or $6 \times 6 = 36$ sections of 720 lb each; $36 \times 720 = 25920$ lb capacity for fish. Movable trucks holding 20 trays (4×6 ft) were planned for each section and no partitions inside will be necessary because the sides of trucks allow adequate separation.

CONCLUSIONS

The results of drying experiments conducted with Cambodian fish show that they can be dried artificially without any difficulty. A good drying rate was obtained because the product is cut and split in such a way as to provide large exposed surfaces.

A product which was judged as first-class quality was obtained with a drying temperature as high as 110°F (43°C). Because the dew point in Cambodia is always between 72.5 and 77°F (22.5 and 25°C), artificial drying without dehumidification is considered to be possible there, provided a temperature of 110°F is used.

ACKNOWLEDGMENTS

The author expresses his sincere thanks to Mr L. Bérubé, Officer of the Colombo Plan, who gave most valuable and detailed information on the situation in Cambodia and who made the arrangements for samples of Cambodian fish to be sent to Canada.

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Probable Effects of Proposed Passamaquoddy Power Project on Oceanographic Conditions[1,2]

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ABSTRACT

The proposed Passamaquoddy power project involves the construction of a series of dams across the mouth of Passamaquoddy and Cobscook Bays. Passamaquoddy Bay, the proposed high pool, will be filled near high water by 90 filling gates, and Cobscook Bay, the proposed low pool, will be emptied near low water by 70 emptying gates. Water will flow continuously from the high pool to the low pool, through a 30-turbine powerhouse. Tidal range will be reduced to approximately 4 and 8 ft in the high and low pools respectively. The effect of this proposed installation on oceanographic conditions in the region has been considered. It is concluded that currents, within the impounded bays and in the area lying inside the Bliss Island–Head Harbour region, will be altered markedly. In the outer Quoddy Region, tidal stream directions will be altered only slightly, while the changes in speed will probably not exceed 20% of their present value. No significant change in residual flow is expected outside the Quoddy Region. Not more than a 1% increase in tidal range is anticipated for the entire Bay of Fundy. Inside the impounded bays, there will be increased stratification. Seasonal variations in temperature of the surface layer will be increased. The summer maximum is expected to reach 20°C and the winter minimum will be less than 0°C. Ice cover is expected to occur over part of the impounded waters. Salinities at the surface will be reduced. Only minor changes in temperature and salinity of the deep layer are anticipated. No significant changes are expected in temperature or salinity in the outer Quoddy Region.

INTRODUCTION

THE ENERGY involved in ocean tides is tremendous, and there has been much speculation upon methods by which useful power might be extracted for man's use. On a small scale, power has been developed by tide-mills in Europe, England and America for several centuries. In recent years serious consideration has been given to large-scale harnessing of the tides, and at the present time a project for the development of tidal power is under way for La Rance River in France. Other schemes have been proposed for the Severn River in England, San Jose in Argentina, Mont St. Michel in France, and portions of the Bay of Fundy in Canada and the United States.

The Bay of Fundy is well known for the extreme tidal range which exceeds 50 ft near its head. This single factor has made it one of particular interest to oceanographers and engineers. The tides of coastal embayments, in general, derive their energy from ocean tides rather than from direct action of lunar and solar gravitational forces. The extreme ranges produced in the Bay of Fundy are attributed to the fact that it has a configuration and physical dimensions

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appropriate to make it a quarter-wave resonator with a period corresponding closely to the period of the semi-diurnal tidal component. This, combined with the narrowing and shallowing in its inner portion, gives rise to a tidal range that increases from approximately 9 ft near its entrance in the Gulf of Maine to greater than 50 ft at its head.

In considering the extraction of power from a tidal system it is wise to consider the probable effects upon the system itself. These effects in many instances are local only. The possibility of widespread effects, however, should not be overlooked in a system which owes many of its characteristics to a resonance phenomenon.

The first serious consideration of a tidal power development involving Passamaquoddy and Cobscook Bays was proposed by a hydraulic engineer, Dexter P. Cooper, in the early 1920's. Studies of the effects that dams in the Passamaquoddy area might have on the oceanography and fisheries of the region were conducted during the late 1920's and early 1930's. In part, the conclusions drawn from these studies (North American Council on Fishery Investigations, Proceedings 1931–1933, No. 2, 1935, p. 6) were as follows:

> "The physical effects of the present mixing mechanism appear to be local and although the construction of the dams would influence the hydrographic conditions in the passages, it is not expected that their influence would extend far into or beyond the outer Quoddy Region.
>
> "The influence of this local mixing on the supply of nutrient salts in the surface layers, where they are available for plant production, is almost entirely confined to the Quoddy Region. The conditions existing over the greater part of the Bay of Fundy appear to result from other factors, which would not be influenced by the dams. It is not considered that the construction of the dams would have an appreciable effect upon the production of plant life outside the Quoddy Region."

In 1956 the governments of Canada and the United States of America referred the problems involved with the Passamaquoddy power project to the International Joint Commission. In turn, the Commission established an Engineering Board and a Fisheries Board to study the problem and report on their findings. (Hart and McKernan, 1960).

In the present study of the Passamaquoddy power project, the basic arrangement proposed by the International Passamaquoddy Engineering Board is a two-pool plan (Fig. 1). It consists of a high pool filled at high tide, a low pool emptied at low tide, and, between the two pools, a powerhouse through which flow from the high pool to the low pool would generate continuous but fluctuating power. The plan involves the impounding of water in Passamaquoddy and Cobscook Bays which would be maintained as the high and low pools respectively.

The proposed physical conditions to be imposed on the area warranted, as a first step, an extensive study of the region to determine the present circulation, tides, distribution of properties, and the controlling or relating factors. The second step was to consider what changes might be expected if dams were installed.

Oceanographic data from the Passamaquoddy region gathered over a period of 50 years prior to 1957, together with extensive observations and measurements taken in 1957 and 1958, were used as a basis for predicting the new conditions that might result from the construction and operation of the power project.

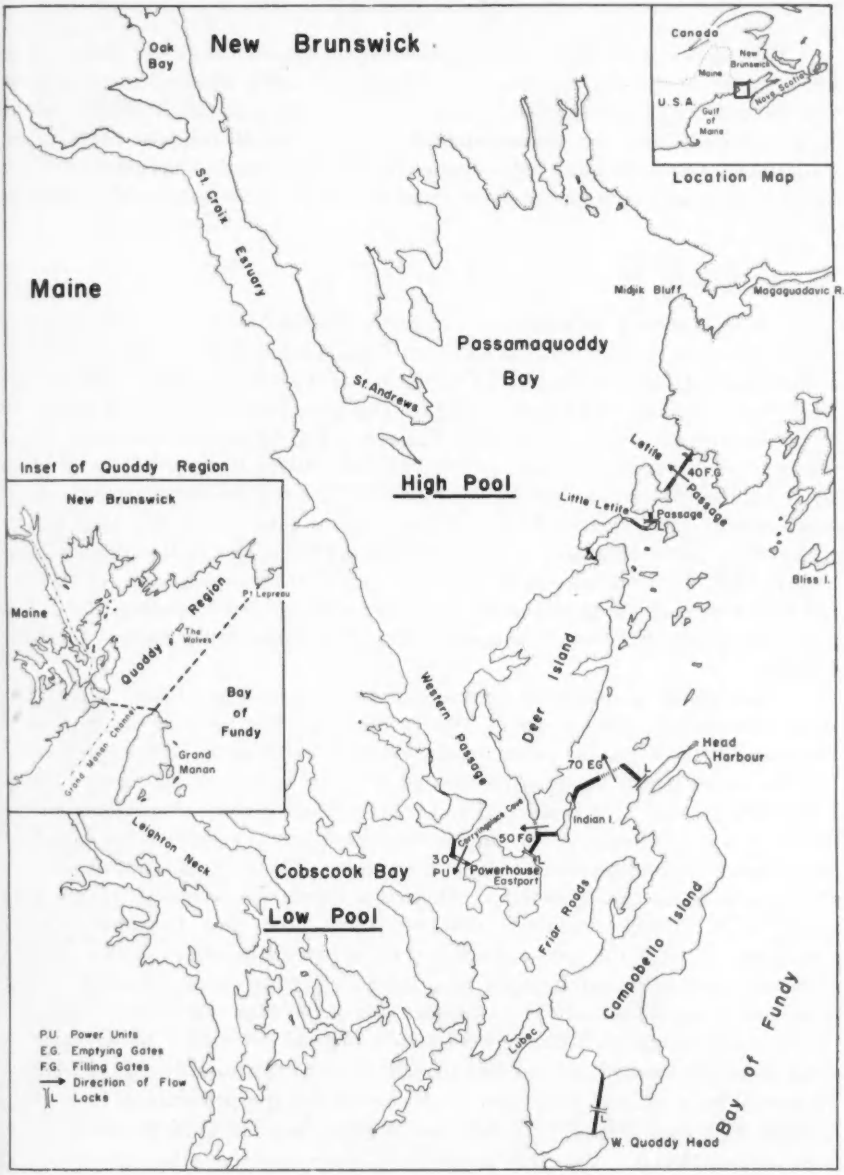

FIG. 1. Map showing location of high pool, low pool, filling gates and powerhouse. The Quoddy Region is shown in inset.

POWER PROJECT

This section deals with those engineering aspects of the power project that are involved in the changes that can be expected in the physical oceanography and the fisheries of the region. In some instances, the material included is in the form obtained from the Passamaquoddy Engineering Board. In other cases, computations from the basic data supplied by the engineers were necessary in order for the material to be in the form required by the Passamaquoddy Fisheries Board.

Project Layout

The final project arrangement selected for detailed design includes approximately 70 sq mi (square nautical miles) of Passamaquoddy Bay as the high pool, and 30 sq mi of Cobscook Bay and Friar Roads as the low pool, with a powerhouse located at Carryingplace Cove (Fig. 1). The plan calls for 90 filling gates, 40 in Letite Passage and 50 in Western Passage. The filling and emptying gates, which are of the same design (Fig. 2-A), are each 30 by 30 ft with a vertical lift set in a venturi throat and placed side by side. The venturi throat permits maximum velocity head and discharge rate for a given gate area. The total length of the filling gates structure in Letite Passage is 1440 ft and in Western Passage, 1800 ft (Fig. 3). The elevations, with reference to mean sea level, of the top and the bottom of the throat of the gates are –10 and –40 ft respectively. The maximum change in pressure in going through the gates would amount to about 4 lb/in^2.

It is planned to install 70 emptying gates between Pope Island and Green Island, occupying a total length of 2520 ft (Fig. 3). The top and the bottom of the throat of the emptying gates are at elevations of –23 and –53 ft respectively.

The minimum cross-sectional area in the flow occurs in the throat, which is 900 ft^2 per gate. The cross-sectional area increases rapidly upstream from the throat, but only slowly in the downstream direction. Velocities are inversely proportional to cross-sectional areas and are given (Fig. 2-B) as ratios of velocity at any point to the throat velocity. Maximum speeds will exceed 24 ft/sec during spring tides. Under maximum flow conditions, the time required to pass completely through the gate structure (110 ft) would be about 6 sec. Where necessary, excavation will be made to a depth of 45 ft on either side of the filling gates, and to approximately 55 ft on either side of the emptying gates.

The Carryingplace Cove powerhouse is planned to consist of 30 turbines rated at 10,000 kw each, placed side by side, occupying a total length of 2400 ft. There will be a channel excavated in the forebay of the powerhouse to connect with the high pool (Fig. 1). It will vary in depth from 33 to 50 ft and in width from 1800 to 2400 ft. Velocities in the channel are expected to be approximately 3 ft/sec.

The plans call for a total of four navigation locks. Two small locks, one in Little Letite Passage and the other near West Quoddy Head, to be 100 by 25 by

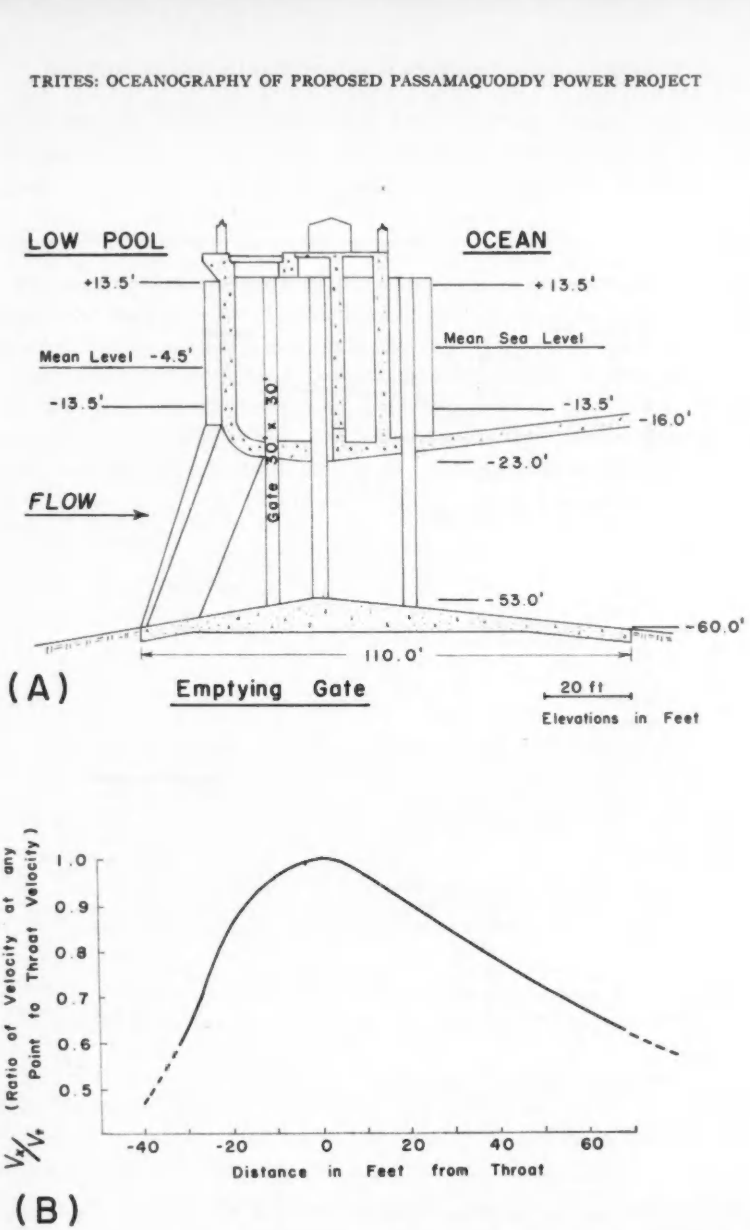

FIG. 2. (A) Cross-section of an emptying gate and (B) ratio of velocity at any point to throat velocity of gate.

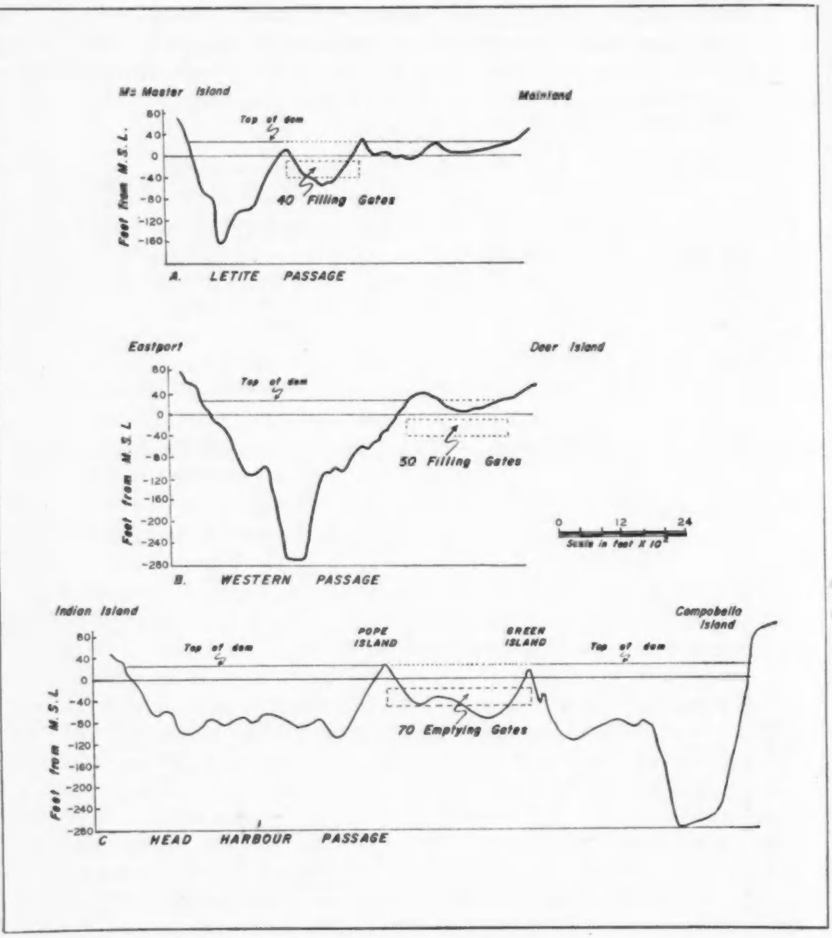

FIG. 3. Cross-sections in Letite, Western and Head Harbour Passages showing location of filling and emptying gates.

10 ft, are designed for small vessels (Fig. 1). Two large locks, one near Wilsons Beach and the other at Eastport, of dimensions 400 by 60 by 21 ft each, are designed to permit access of large vessels to both the low and high pools.

Cycle of Operations

The principle of operation is to maintain a hydraulic head between the high pool and the low pool. The high-pool filling gates will be opened only during times when the water level outside is higher than the level of the high pool. The emptying gates will be opened only when the level outside is lower than the level of the low pool. Water will flow continuously from the high pool through turbines to the low pool. The time variations in water level in the high pool, low pool and outside, are shown in Fig. 4. The sequence of events for a 12.4-hr cycle would be:

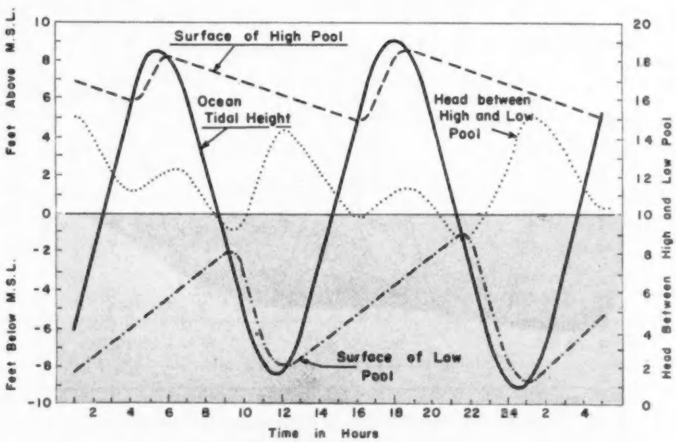

Fig. 4. Daily cycle of power project operation showing head between high and low pools, and the variation in water level for the high pool, low pool and outside areas.

1. The filling gates are closed soon after high water, when the inflow ceases and the level in the high pool is equal to the level outside. At this stage the high pool is at its greatest elevation.

2. Both filling and emptying gates remain closed (2.5-hr period) until the level outside falls to the level of the low pool at which time the emptying gates are opened. At this stage the low pool is at its maximum elevation.

3. The emptying gates are closed (3.4-hr period) soon after low water when the level of the low pool is the same as the level outside. At this point the low pool is at its minimum elevation.

4. Both filling and emptying gates remain closed (3.5-hr period) as the tide outside rises, until the elevation of the high pool and that outside become equal, when the filling gates are opened. At this point the high pool is at its minimum elevation.

5. The filling gates remain open (3.0-hr period) until conditions in paragraph 1 above exist, which completes the 12.4-hour cycle of operation.

Water Levels and Flow Conditions

In Fig. 5 the time variations in water levels are shown respectively for spring tide, mean tide and neap tide in the high pool, low pool and open ocean. The

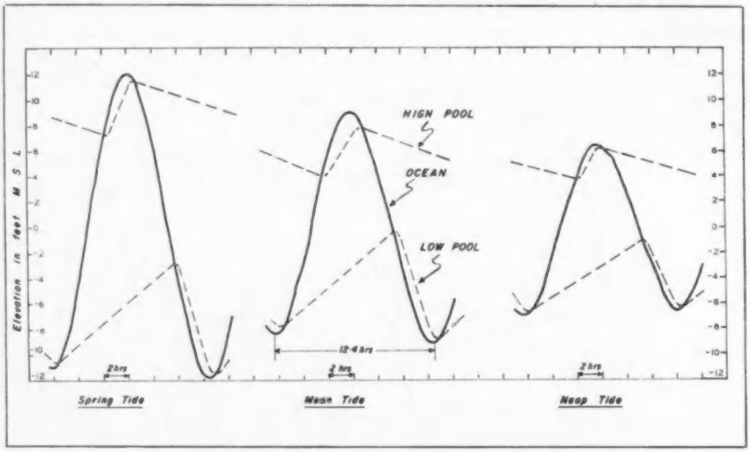

Fig. 5. Time variations in water levels in high pool, low pool and open ocean for spring, mean and neap tides.

open ocean tides shown are predicted ones for Eastport, Maine. For the spring tide the falling range is 24 ft. This range is exceeded in 1% of occurrences. For mean tide the falling range is 18.2 ft (exceeded in 45% of occurrences), and for neap tide the falling range is 13 ft (exceeded in 98.3% of occurrences).

Mean level will be raised in Passamaquoddy Bay about 6.4 ft and lowered in Cobscook Bay about 4.5 ft. The mean range in the high pool and the low pool will be 3.6 and 7.7 ft respectively.

During spring tides the average water level in the high pool will be raised 8.5 ft and will have a range of 4.4 ft. The maximum level reached in the high pool will be reduced 1.4 ft as compared to the level outside. The water level in the low pool will be lowered 6.2 ft and will have a range of 9.5 ft. At low water the level inside the low pool will be about 0.5 ft above the level outside.

During mean tides the average water level in the high pool will be raised 6.0 ft and will have a range of 3.9 ft. In the low pool the average water level will be lowered 4.0 ft and will have a range of 8.4 ft.

During neap tides the average water level in the high pool will be raised 4.6 ft and will have a range of 2.6 ft. In the low pool the average water level will be lowered 3.8 ft and will have a range of 5.3 ft.

In the high pool, the minimum elevation, which will occur during neap tides, and the maximum elevation, which will occur during spring tides, will be respectively 3.2 and 10.6 ft above the present mean sea level (Fig. 6).

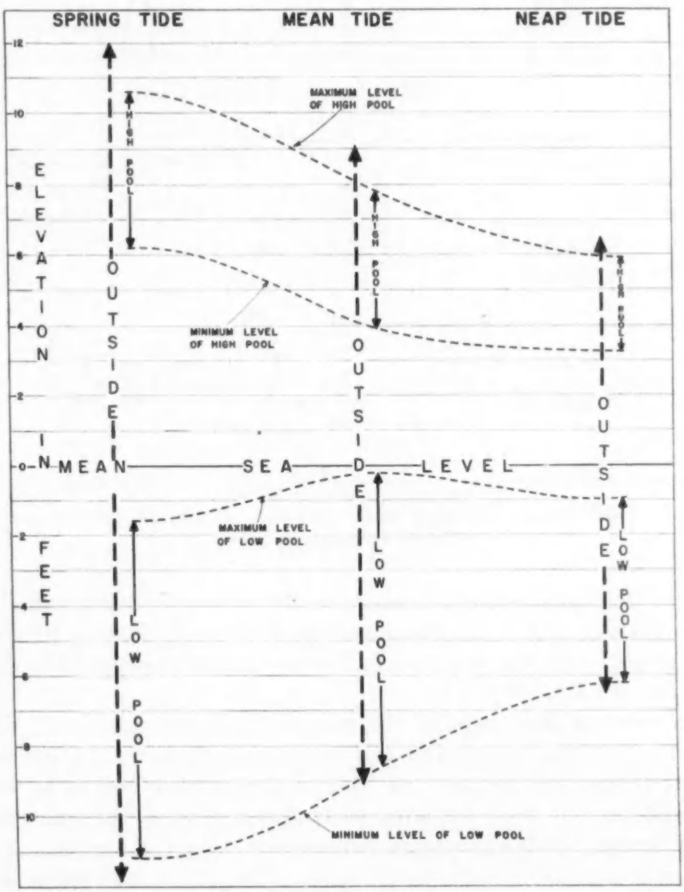

FIG. 6. Schematic illustration showing elevations and ranges of water levels in high pool, low pool and outside areas, for spring, mean and neap tides.

In the low pool the maximum elevation will occur during mean tides and the minimum elevation during spring tides. These will be respectively 0.0 and −11.4 ft relative to present mean sea level.

Flow through the filling gates, discharge through the turbines, and flow through the emptying gates, are shown in Fig. 7 for spring tide, mean tide and

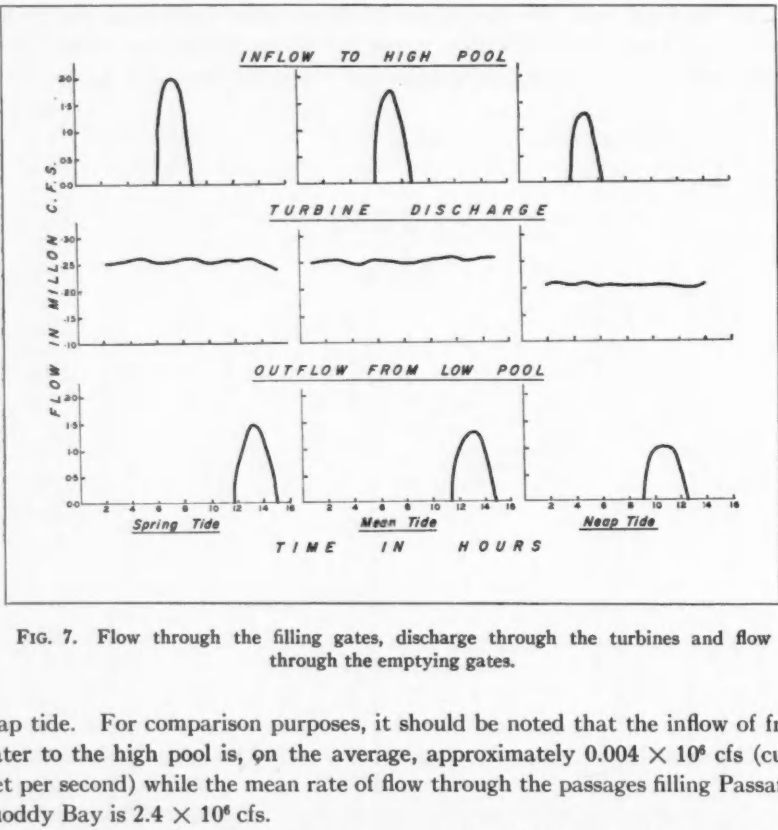

FIG. 7. Flow through the filling gates, discharge through the turbines and flow through the emptying gates.

neap tide. For comparison purposes, it should be noted that the inflow of fresh water to the high pool is, on the average, approximately 0.004×10^6 cfs (cubic feet per second) while the mean rate of flow through the passages filling Passamaquoddy Bay is 2.4×10^6 cfs.

The hydraulic head between the two pools will fluctuate during the cycle of operation between two maxima and two minima (Fig. 4). Maximum heads will occur at high tide and low tide while minimum heads will occur when the level outside is near mean sea level, on both the rising and falling tide. The head will fluctuate from a maximum during spring tides of nearly 20 ft to a minimum during neap tides of only 6 ft (Fig. 5). The average head will be approximately 12 ft. Flow through the powerhouse will average 0.285×10^6 cfs but will decrease to approximately 0.2×10^6 cfs for minimum flows.

POWERHOUSE

A cross-section of the Carryingplace Cove powerhouse through the centerline of one of its thirty 10,000-kw turbines is shown in Fig. 8. Each turbine has a vertical axis, fixed blades, a diameter of 320 inches, and turns at 40 rpm.

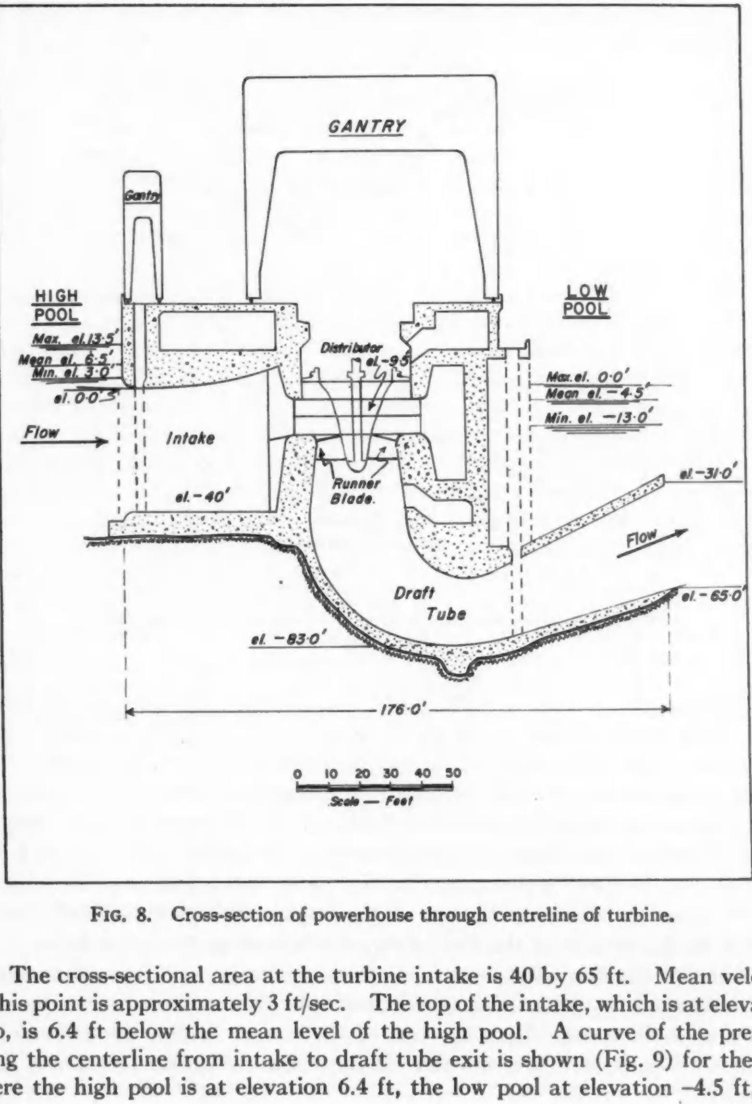

FIG. 8. Cross-section of powerhouse through centreline of turbine.

The cross-sectional area at the turbine intake is 40 by 65 ft. Mean velocity at this point is approximately 3 ft/sec. The top of the intake, which is at elevation zero, is 6.4 ft below the mean level of the high pool. A curve of the pressure along the centerline from intake to draft tube exit is shown (Fig. 9) for the case where the high pool is at elevation 6.4 ft, the low pool at elevation –4.5 ft, and

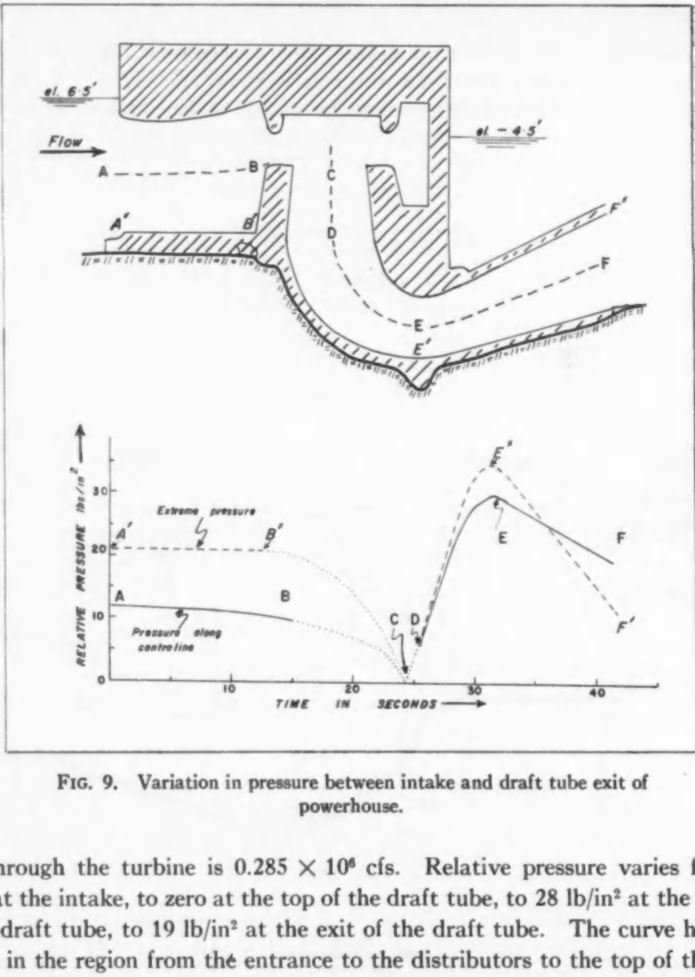

FIG. 9. Variation in pressure between intake and draft tube exit of powerhouse.

flow through the turbine is 0.285×10^6 cfs. Relative pressure varies from 13 lb/in² at the intake, to zero at the top of the draft tube, to 28 lb/in² at the bottom of the draft tube, to 19 lb/in² at the exit of the draft tube. The curve has been dotted in the region from the entrance to the distributors to the top of the draft tube, since adequate data to permit reliable calculations were not available. In order to indicate the most extreme conditions, a dashed curve has been constructed (Fig. 9) showing the approximate pressure that a fish would be subjected to if it passed in along the bottom of the intake, through the distributor and turbine to the bottom of the draft tube, finally leaving the powerhouse at the top of the draft tube. The most rapid pressure changes will occur between the distributors and the top portion of the draft tube, where pressure will change as rapidly as 7 lb/in²/sec. Near the tips of the runner blades, the pressure will drop below atmospheric pressure and will approach the vapour pressure of water as the limit.

Present Circulation, Tides and Distribution of Properties

The oceanographic features of the Bay of Fundy are determined by the tide-producing forces, the earth's rotation, the fresh water discharged by the rivers, the meteorological conditions, and the bottom configuration. Of these factors, the tidal currents and amplitudes are dominant. Due to the strong tidal currents, which exceed 8 ft/sec in restricted areas (Forrester, 1960), vertical mixing of the water proceeds vigorously and hence seasonal fluctuations in temperature and salinity of the surface layer are much reduced.

One of the earliest systematic oceanographic surveys in the Bay of Fundy consisted of tidal current measurements by Dawson (1908). Since then, an extensive body of data has been collected, which has enabled a general description of the non-tidal circulation, and the spatial and temporal distribution of temperature and salinity. Copeland (1912), Craigie (1916), Vachon (1918), Hachey (1934c), Watson (1936), Hachey (MS, 1957) and Bailey (MS, 1957), have each dealt with certain aspects of Passamaquoddy Bay. Various studies of the oceanographic features of the Bay of Fundy have been published by Craigie and Chase (1918), Mavor (1922, 1923), Hachey (1934b), Watson (1936), Fish and Johnson (1937), McLellan (1951), MacGregor and McLellan (1952), Ketchum and Keen (1953) and Bailey *et al.* (1954). As a result of these studies, a comprehensive and valuable body of information is available concerning the gross features of temperature, salinity, circulation, and certain of the interrelationships and controlling factors have been established. Difficulty has been experienced, however, both in establishing with clarity the non-tidal circulation in the Quoddy Region (i.e., the area lying inside a line drawn from West Quoddy Head, Maine, to the northern tip of Grand Manan Island thence to Point Lepreau, N.B.), and in discovering any systematic relationship with the controlling factors. In order to provide a better understanding of the oceanographic features of the area, extensive field measurements were undertaken in 1957 and 1958. In the field program, direct current measurements were taken from an anchored ship at selected stations, temperature and salinity observations were made spatially and temporally throughout the region, electromotive force recorders were installed across some of the passages to determine transports, drift poles mounted with radar reflectors were tracked, and drift bottles were released at regular intervals throughout the area. In addition, surface samples were taken twice daily at the Biological Station wharf, St. Andrews, N.B. An anemometer was installed at Point Lepreau, N.B., and a tide gauge at the Government wharf at St. Andrews.

Tides and Tidal Currents

The remarkable tides in the Bay of Fundy have been attributed, in part, to the fact that the physical dimensions of the area are such that the natural period of vibration (quarter-wave) is approximately equal to the semi-diurnal tidal component.

The tide in a basin with one end closed and the other end in communication with the ocean is known as a co-oscillating tide. Fruitful results can be obtained

by considering the tides to be the resultant of a primary progressive wave and its reflected counterpart, with both undergoing damping due to frictional effects. Redfield (1950) made an analysis of the Bay of Fundy tides using the above approach and was able to relate the tidal range, time of high water, time of slack water, and phase difference of the primary and reflected waves throughout the bay for different coefficients of damping. In his conclusions, he suggested that "exceptional tidal ranges observed in such embayments as the Bay of Fundy are due to two or more stages in amplification by the combined effects of reflection and resonance in systems successively tributary to one another and to the ocean".

An investigation on the influence of the proposed tidal power project on the tides in the Bay of Fundy was carried out by Ippen and Harleman (MS,1958). They approached the problem of describing the Bay of Fundy system in a manner similar to that of Redfield (1950) and then attempted to establish the relative "sensitivity" of the sytem to disturbances such as the proposed power project would involve. It is interesting to note that although two of the abovementioned papers adopt a similar approach in describing the Bay of Fundy tidal system, the seaward end of the Bay of Fundy chosen for the analysis varies significantly. In Redfield's analysis, he considered the Bay of Fundy tidal system to conform satisfactorily to the theoretical expectation from the head of Chignecto Channel and the entrance to Minas Basin (where a point of reflection appears to be located) to a seaward point located in the vicinity of Lower East Pubnico in the southwestern part of Nova Scotia. The phase change undergone by the primary wave between these limits is about 80°. In the analysis made by Ippen and Harleman the seaward boundary was chosen at a point where the phase shift is only 68° and the amplification of the tide from ocean entrance to the head of the bay is two and one-half times. This compares to an amplification factor of approximately four in Redfield's analysis.

The net result of resonance combined with narrowing and shoaling in the inner reaches of the Bay of Fundy is that the tidal range increases from approximately 9 ft in the Gulf of Maine to greater than 50 ft at the head of Minas Basin. In the Quoddy Region the mean range of the tide varies from about 16 ft at West Quoddy Head to 20 ft near the head of the St. Croix estuary. The extremes vary from approximately 14 ft at neaps to a maximum of nearly 28 ft at springs. The mean range in the region is taken as 18 ft. Differences in the time of occurrence of high or low water throughout the Quoddy Region are less than an hour.

Tidal currents in most areas of the Bay of Fundy are nearly rectilinear, reversing direction approximately every 6 hr (Forrester, 1960). Speeds vary widely from place to place throughout the area, with currents in restricted passages, such as Letite, reaching a mean maximum value of 8 ft/sec. In Passamaquoddy Bay speeds are mostly less than 1 ft/sec. In Cobscook Bay mean maximum speeds near the mouth are approximately 5 ft/sec. In the region beyond the passages and bays (outer Quoddy Region) speeds seldom exceed 5 ft/sec. Speeds recorded were usually a maximum at the surface and decreased slowly with depth. In Fig. 10 and 11, the tidal streams at the surface are shown

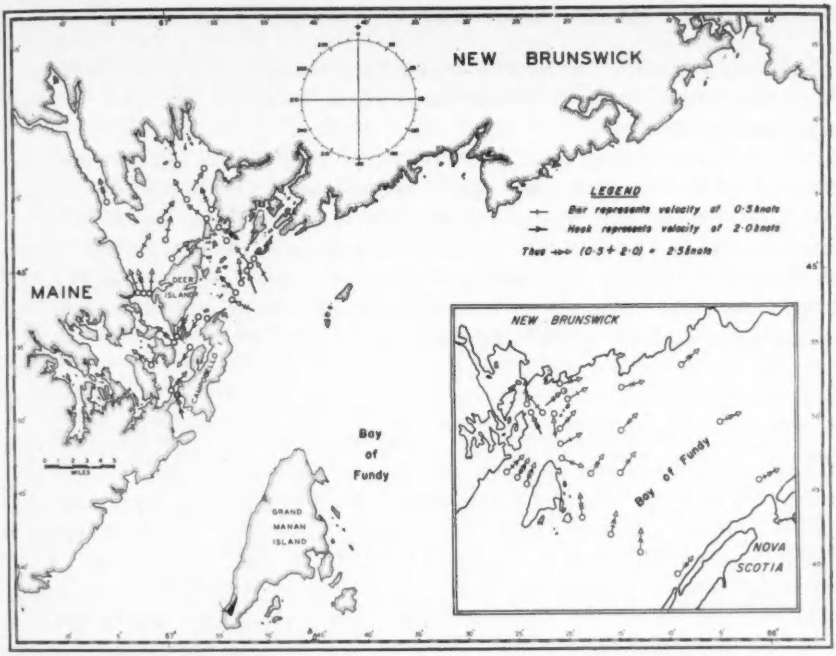

FIG. 10. Tidal streams in Passamaquoddy Bay and Bay of Fundy at half ebb (high water plus 3 hours).

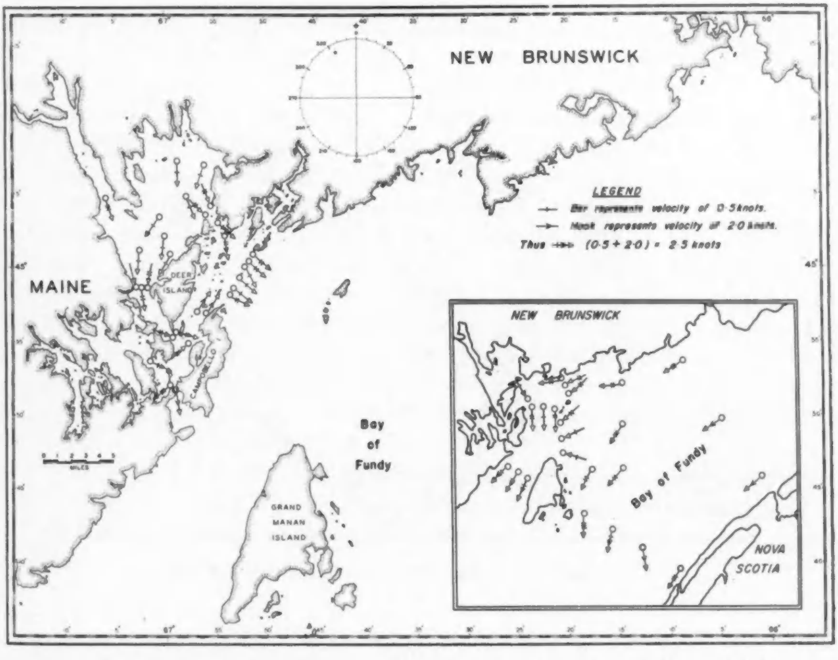

FIG. 11. Tidal streams in Passamaquoddy Bay and Bay of Fundy at half flood (high water minus 3 hours).

for two periods, one at 3 hr before low water, and the other at 3 hr after low water with reference to Saint John Harbour. These were near the time of mean maximum speeds.

Times of slack water occur later in Western Passage than in Letite and vary from 15 to 60 min with some degree of periodicity (Trites and MacGregor, MS, 1959). More than 60% of the intertidal flow into Passamaquoddy Bay is through Western Passage. Peculiarities in the shape of the tidal current curves, as determined by the electromagnetic method (Trites and MacGregor, MS, 1959), suggest the presence of harmonics of the semi-diurnal component and appear to be related to shallow-water effects.

Residual Flow

The surface non-tidal circulation in the main portion of the Bay of Fundy is in a counter-clockwise direction (Fig. 12). Inflowing waters from the open ocean hold close to the Nova Scotia coast, while the outflowing waters pass out off the southeast coast of Grand Manan and thence either along the coast of Maine or across the mouth of the Bay of Fundy to the Nova Scotia coast. There is some evidence of seasonal variation in the pattern of flow in the Bay of Fundy (Chevrier and Trites, 1960; Bumpus, 1960). Residual flows are usually less than 2 mi/day in Passamaquoddy Bay, Cobscook Bay, and the approaches. In the Bay of Fundy, flows are variable and at times, in some areas, exceed 10 mi/day (Bumpus *et al.*, 1957; Chevrier and Trites, 1960; Forrester, 1960).

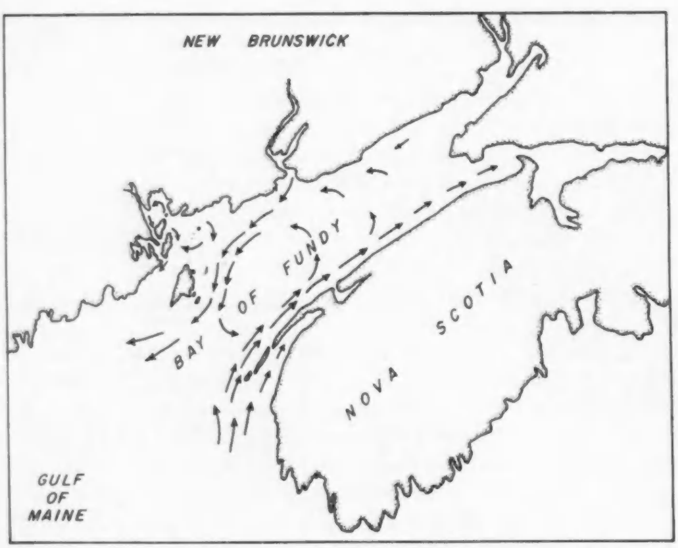

Fig. 12. Non-tidal surface circulation in the Bay of Fundy.

Inside Passamaquoddy Bay, the surface circulation, on the average, appears to be in a counter-clockwise direction around the periphery. Frequently two cyclonic eddies are evidently present, the larger one in the eastern side of the bay, and a smaller one in the Western part of the bay. A relatively free exchange of water occurs between the eddies. There is evidence that the wind modifies this situation markedly. On the whole, wind action is very effective in moving waters of the upper layers and this in turn influences the deeper circulation. In general, it is concluded that winds with a southerly component tend to confine surface waters to Passamaquoddy Bay, while winds from the north and west remove surface waters from the bay. In each instance, there must be a compensating flow at subsurface levels. Since winds vary seasonally in strength and direction from a dominant southwest direction during summer months, to north in winter months, a corresponding effect on circulation in Passamaquoddy Bay can be expected. No clear picture of the net flow through Letite and Western Passages has been established. There is evidence that, on the average, the net flow is outward through Western and inward through Letite. However, there are instances when the net flow appears to be reversed and also times when surface flow is in the same direction in both passages. From theoretic and dynamic considerations, however, it is concluded that the surface water in Western Passage must on the average move outward.

Since Cobscook Bay has very little fresh water discharged into it (average approximately 300 cfs) there is little reason to suspect any marked residual flow. Wind direction and speed, and heating and cooling of the extensive mudflats in the bay, undoubtedly play a role in determining the residual flow. Drift bottles released in the bay usually moved out. It was not uncommon, however, to find that a bottle released outside the bay moved to the inner reaches of Cobscook Bay.

The residual flow through Grand Manan Channel is variable, and it is suggested that winds play an important role in determining the magnitude and direction of flow. Only along the coast of Maine is there evidence indicating that the net flow, at most times, is southwestward.

The circulation in the vicinity of The Wolves has not been determined with certainty. This area, which lies in the offing to the passages, is one where the motion is extremely complex, and difficulty was experienced in measuring the tidal streams with confidence, let alone the residual flow (Forrester, 1960). On the basis of drift-bottle experiments (Chevrier and Trites, 1960), however, there is evidence that an eddy frequently exists, which rotates slowly in a clockwise direction. At other times, this eddy is not evident, and the flow between The Wolves and the mainland reverses direction.

It is concluded that the net flow from the Quoddy Region is, on the average, small. The very marked residual flow resulting from the seaward movement of mixed waters from the Saint John River skirts past Point Lepreau and the Quoddy Region.

Temperature and Salinity

Due to the strong tidal currents vertical mixing of the water proceeds vigorously and hence the seasonal fluctuations in temperature and salinity of the surface layer are relatively small. In the Quoddy Region, the mean annual range of temperature and salinity of the surface layer is approximately 1 to 12°C and 30 to 33‰ (Forgeron, MS, 1959). For inshore areas and in Passamaquoddy Bay the seasonal variations are slightly greater than in the offshore and deep waters. The seasonal pattern of temperature and salinity for two stations, one inside Passamaquoddy Bay and one in the outer Quoddy Region, is shown in Fig. 13.

Mixing in the passages is particularly intense and the water is nearly homogeneous vertically. Grand Manan Channel and the area south and southwest of Grand Manan are areas of very low stratification where the well-mixed waters of the Bay of Fundy are subject to additional local mixing. The greater part of the mixing seems to take place in the shoal area at the southern extremity of the channel and the well-mixed waters are carried northward during the flooding tide. A significant amount of mixing also takes place in the vicinity of Long Eddy Point and West Quoddy Head (McLellan, MS, 1951).

TIDAL PRISM TECHNIQUE

Ketchum (1951) developed a technique for predicting the accumulation of fresh water and mean distribution of salinity in an estuary. To apply the method it is necessary to subdivide the estuary into segments which are horizontally defined by the width of the estuary and the average excursion of a particle of water on the flooding tide. He tested his theory by using data from several areas with vastly different characteristics of tidal range, length of estuary, depth and fresh water discharge. The technique was applied to the St. Croix estuary, Passamaquoddy Bay, and the entire Bay of Fundy (Ketchum and Keen, 1953). The predicted accumulation of fresh water in the St. Croix estuary agreed closely with observation. Flushing times were calculated for the St. Croix estuary and the Magaguadavic estuary from observations taken in June and August 1958. From 43 cruises made in the Quoddy Region in 1957 and 1958, flushing times on a seasonal basis were computed for Passamaquoddy Bay (Forgeron, MS, 1959).

The tidal prism theory assumes complete vertical mixing of the water column, and complete horizontal mixing within each tidal segment. Ketchum (1951) found that in some estuaries the column was incompletely mixed, or that mixing was complete for only a portion of the water column.

Ketchum and Keen (1953) using data taken in August 1951 computed the flushing times of various segments of the St. Croix estuary and found them to vary from a little more than one tidal cycle for the segment near Calais to about three

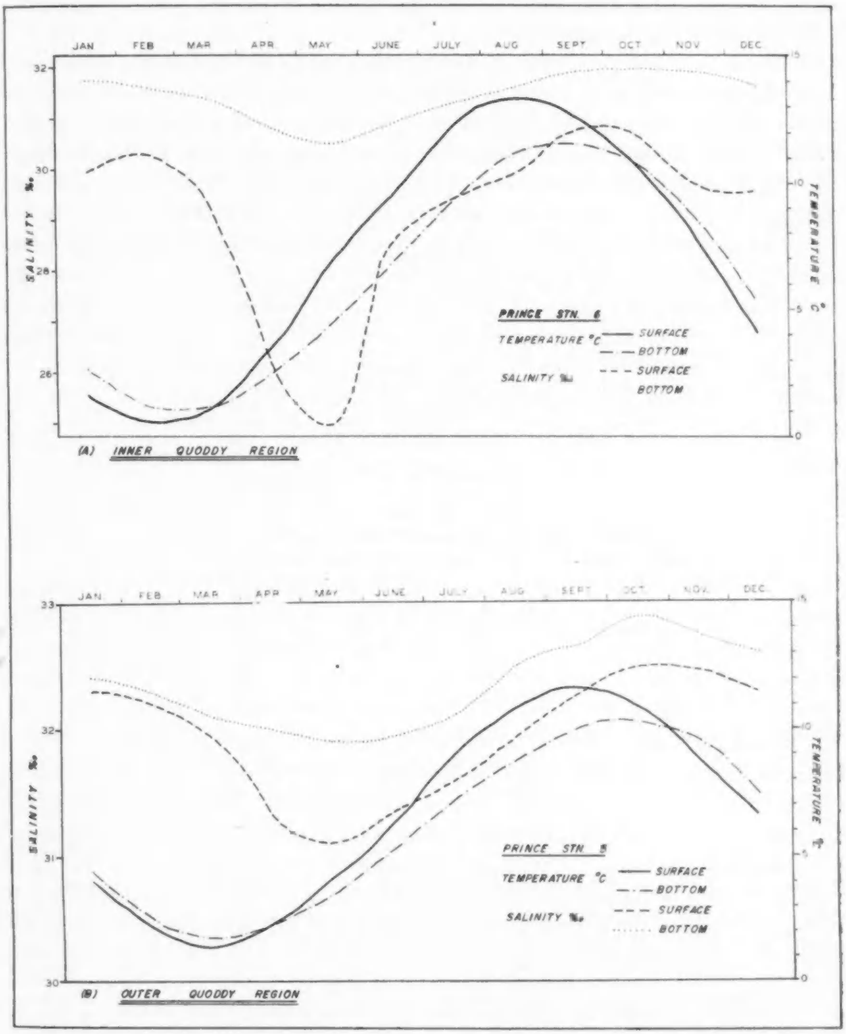

FIG. 13. Seasonal variations in salinity and temperature of surface and bottom waters in inner and outer Quoddy Region.

tidal cycles near St. Andrews. For the entire length of the estuary about 8 days were required to remove one day's river flow. Values computed from observations taken in June and August 1958 (Forgeron, MS, 1959), indicated flushing times of 7 and 6 days respectively.

To aid in the prediction of expected conditions in the St. Croix and Magaguadavic estuaries, if the proposed power project was installed, the tidal prism technique was applied to these estuaries under the new conditions. Sets of salinity distributions were calculated using different mixing hypotheses. From consideration of other areas (Ketchum, 1951; Trites, MS, 1955), it was felt that the most realistic calculation was obtained by considering mixing to penetrate to 10 ft and uniform tidal currents down to 20 ft. The flushing time for the St. Croix estuary, using these conditions and a river discharge of 9.7×10^7 ft^3 per tidal cycle, was calculated to be 12 days. By assuming mixing to be complete in the upper 20 ft and velocities zero below 20 ft, the flushing time was computed to be 22 days. In both these cases, it should be noted that a substantial increase in the flushing times from present conditions is predicted. The salinity and percentage of fresh water in the mixed layer for each segment, for the above conditions, are shown in Table I.

TABLE I. Salinities predicted for the mixed layer in the St. Croix estuary, between Calais and St. Andrews, using tidal prism technique, for a river discharge of 9.7×10^7 ft^3 per tidal cycle, and a base salinity of 32‰.

Segment:	0	1	2	3	4	5	6
Miles from head (Calais)	2.6	4.7	6.0	8.6	10.4	12.6	13.8
Fresh water, %	100	97	95	38	30	26	20
Salinity, ‰	0	1	2	19	22	24	26

Attention is drawn to the fact that the predicted salinities are mean values. In applying the technique, mixing is assumed to be complete over a given depth. Under natural conditions this is frequently not the case. Surface salinities may be substantially lower than the mean salinity of the seaward-moving surface layer.

The flushing time of the Magaguadavic estuary above Midjik Bluff was computed from temperature and salinity observations taken in June and August 1958 and found to be approximately 2 days. The predicted time, for the new conditions, assuming mixing to be complete to 10 ft and tidal velocities zero below 20 ft, was found to be approximately 5 days.

For the remainder of the high pool Ketchum's prediction technique is not feasible, since it is not a simple estuary with tidal currents oscillating. The location of filling gates in Letite Passage imposes a dominant residual flow in the high pool. The water entering these gates was considered in the same manner as if it were "fresh" water, but it proved unrealistic to carry out segmentation of the high pool, as developed by Ketchum.

OTHER AREAS WITH FEATURES SIMILAR TO PASSAMAQUODDY BAY AFTER DAMS ARE INSTALLED

Kennebecasis Bay

Kennebecasis Bay, N.B., is a body of water largely cut off from the sea by a sill near the mouth of the Saint John River. A study of this bay and the Saint John estuarial system was undertaken in 1957 and 1958, since it was conceivable that the physical and biological conditions in this bay are similar to those that might be expected in Passamaquoddy Bay in the event that power dams were installed across its mouth (Trites, 1960).

From this study it was readily apparent that there is a degree of similarity between Kennebecasis Bay and Passamaquoddy Bay when dammed. However, there is one factor that is strikingly different for the two situations. In Passamaquoddy Bay virtually all of the fresh water enters the system from the head of the bay. The fresh water discharged into Kennebecasis Bay at or near its head is comparable to the discharge into Passamaquoddy Bay, but the mouth of the Kennebecasis joins the Saint John River which has an annual discharge approximately 20 times larger than the inflow at the head of Kennebecasis Bay. This influences in large measure the distribution of properties within Kennebecasis Bay. Two sills separate the deep water in Kennebecasis Bay from the Bay of Fundy. The result is that the salinity of the deep layer is nearly 10‰ less than in the Bay of Fundy. Under the conditions of Passamaquoddy Bay with dams installed, there is just one sill, and compared to Kennebecasis Bay which has a large fresh water source at its mouth, there is virtually no fresh water source on the Bay of Fundy side of the filling and emptying gates. It is concluded therefore, that the distribution of properties found in Kennebecasis Bay represents more extreme conditions than will be encountered in Passamaquoddy Bay in the event that power dams are installed. The results of this study are valuable, however, in assisting to bracket the most extreme conditions probable in Passamaquoddy Bay under new conditions.

Oak Bay

Oak Bay, N.B., is an area of the St. Croix estuary (Fig. 14). A few years ago, a portion (approximately 50 acres) of this bay was partially cut off from the sea by a causeway which reduced the tidal exchange. Three conduits, 5 ft in diameter, permit water to flow in during about a 3-hr period near high water. The tidal range is 1 to 2 ft. A small river with a drainage basin of 9 sq mi discharges into the impounded bay. Physically, therefore, there is some similarity between Oak Bay inside the causeway and Passamaquoddy Bay when dammed.

The shellfish investigation of this Board's Biological Station at St. Andrews, N.B., has been studying the area during the past 3 years, and has kindly made data available (J.C. Medcof, personal communication).

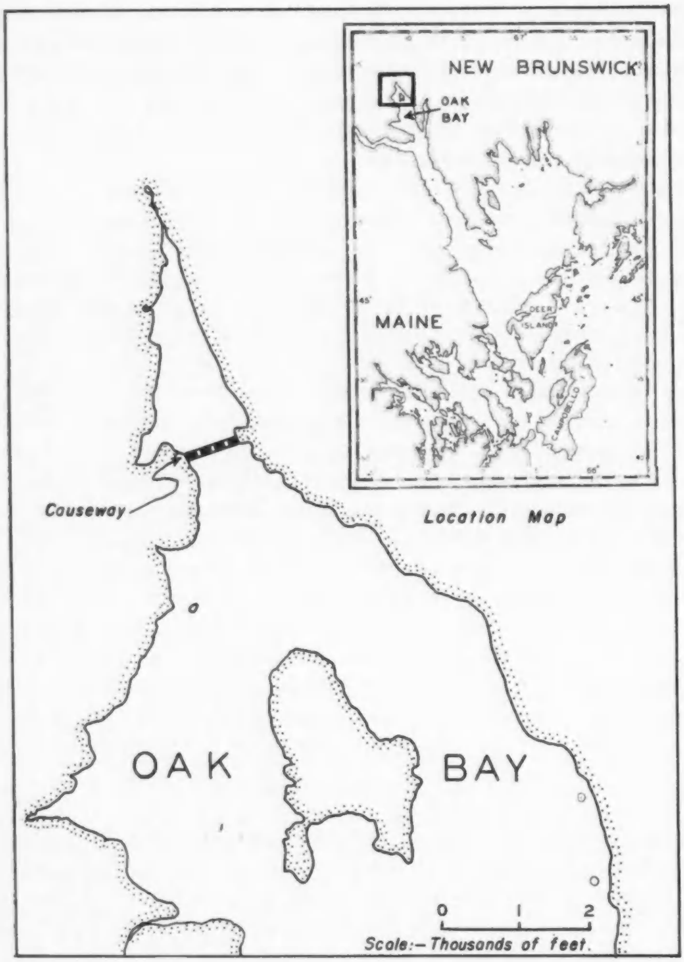

FIG. 14. Oak Bay, showing locations of Causeway.

The salinity and temperature of the bottom water inside the causeway (maximum depth approximately 13 ft) follow closely those outside the causeway, which fluctuate seasonally from about 12 to 30‰ and from 0° to 18°C respectively. Low salinities occur for a brief period during the spring freshet. The surface layer is usually less than 1 ft thick, and varies seasonally in salinity from 1 to 25‰. Maximum recorded depth of surface layer was approximately 3 ft. Temperature of the surface water varies seasonally from less than 0°C in winter to a mean monthly maximum of about 19°C in summer. Ice usually forms in December and except for a small ice-free area near the conduits, remains until March or April. Ice thickness varies from a few inches to greater than a foot during prolonged cold periods. Sufficient observations have not been taken to determine a reliable summer maximum, but the maximum recorded in 1958 was 18.0°C whereas in the previous year it was 20.6°C.

Gulf of St. Lawrence

Tidal amplitudes in the southwestern Gulf of St. Lawrence are similar to those predicted for the new conditions in Passamaquoddy Bay. Mixing due to tidal currents and wind action may on the whole be somewhat more effective in the gulf. Tidal currents in Northumberland Strait reach values of 1 to $1\frac{1}{2}$ knots, and the tidal range is approximately 5 ft. Daily water temperatures, taken at Port Borden, P.E.I., indicate that the mean monthly water temperature ranges from −1.4°C in February to 18.9°C in August (Lauzier, MS, 1953; unpublished data from files, Biological Station, St. Andrews, N.B.). At Ellerslie, Malpeque Bay, P.E.I., minimum temperatures are similar to those at Port Borden, but summer mean maxima reach 21.6°C in July. The mean tidal range is $2\frac{1}{2}$ ft.

In Northumberland Strait, ice usually forms early in December in the shallow harbours. By January the entire strait has fairly heavy ice conditions due in part to ice having moved in from the north. The break-up usually occurs in April (Forward, 1954).

British Columbia Inlets

An examination of British Columbia inlets is instructive from the point of view of the depth of penetration or thickness of the brackish layer that might be expected in Passamaquoddy Bay. In general, the British Columbia inlets are relatively deep, long, and narrow. The wide ranges of fresh water discharge and tidal currents encountered from inlet to inlet make comparisons with Passamaquoddy Bay worth while. One relatively small inlet (Loughborough) may be taken for illustrative purposes. This inlet has a length of 30 miles and an area of 26 sq mi (Trites, MS, 1955, MS, 1956). The tidal range averages about 12 ft and tidal currents at about midway from the head to the mouth of the inlet are less than 1 ft/sec. The supply of fresh water (yearly average 3430 cfs) during July is approximately 5120 cfs, or 200 cfs/sq mi or 6000 cfs/unit width of inlet. The salinity distribution indicates a surface layer about 7 ft thick and a salinity of

5‰ near the head, about 15‰ at mid-inlet, and 28‰ near the mouth. The thickness of the brackish layer decreases slightly to seaward. In Passamaquoddy Bay the average discharge per square mile is about 40 cfs, which is small compared to that in Loughborough Inlet. Tidal currents appear to be similar in the two areas, but due to the larger fresh water discharge and the dissimilar shapes, one would expect Loughborough Inlet to represent more extreme conditions than might be encountered in Passamaquoddy Bay as a whole under new conditions.

A comparison with only a part of Passamaquoddy Bay, however, indicates a closer similarity to conditions in Loughborough Inlet. The St. Croix estuary, above St. Andrews, has a length of approximately 13 mi and an area of 11 sq mi. The average annual discharge is approximately 2200 cfs, which is equivalent to a discharge of 200 cfs/sq mi and 2600 cfs per unit width. Although the St. Croix estuary is shorter, its discharge per square mile is similar to that of Loughborough Inlet in July.

An examination of several other British Columbia inlets revealed that even for discharges more than five times that of the St. Croix estuary, the depth of penetration of significant proportions of fresh water never exceeded about 33 ft.

DISCUSSION

In the oceanographic study of the Quoddy Region the general features of the tides, circulation, and distribution of properties have been described, but only a qualitative evaluation of the controlling factors has been possible. Without a moderately precise relationship between controlling factors and the circulation, etc., it is impossible to make precise predictions as to what will happen under a new set of controlling factors. Study of the previously mentioned pertinent aspects of other areas, in which some of the factors including tidal amplitude, fresh water discharge, depths and areas bear a degree of similarity to the proposed new conditions imposed on the Quoddy Region, was considered instructive and has facilitated the drawing of conclusions.

Under the proposed project the water level in the high pool will have a "tidal" range averaging 4 ft compared with the present 20 ft. In the low pool the average range will be 8 ft. Outside, the tidal amplitude will be modified only slightly. In the impounded bays, the flow of water will be reduced and consequently vertical mixing will be much reduced. The effect of reduced vertical mixing is twofold, and in each case the tendency will be for increased stratification of the water and a consequent greater seasonal variation in the temperature and salinity of the surface layer.

Flow Conditions

High pool. For approximately 9½ of 12½ hr the filling gates will be closed. Water will leave the high pool continuously through the turbines and therefore the motion in Passamaquoddy Bay will be towards Western Passage, where the water is discharged into Cobscook Bay (Fig. 1).

The channel leading to the powerhouse will be approximately 45 ft deep. On the average it would appear that the bulk of the motion in the high pool will occur in the upper 45 ft of the water column. Under these conditions the water level will drop 4 ft in 9 hr compared to the present 19 ft in 6½ hr. Mean velocities should therefore be reduced to approximately one-sixth their present value. However, considering that the bulk of the motion is likely to be confined to the upper 45 ft the mean velocities in this layer will probably be reduced to one-quarter or one-fifth their present values. The present proportion of water entering Western Passage to the total flow into Passamaquoddy Bay is roughly 60%. Under the proposed plan this proportion will be reduced slightly to 55%. During the periods the filling gates are open, velocities in most areas of the high pool should be similar to, but slightly lower, than those of the corresponding present conditions, since the filling rate is only slightly less than the present flooding tide rate (Fig. 4).

At present the residual flow relative to the tidal flow is very small. Under the proposed conditions, the flow in Letite Passage will be unidirectional, and hence on a relative basis at least, the residual flow in Passamaquoddy Bay will be more dominant than at present. A general counter-clockwise circulation in the bay can be expected. The possibility of an eddy in the northeastern part of the bay, and partially distinct from the larger-scale counter-clockwise circulation, cannot be ruled out.

In the estuaries of the St. Croix and Magaguadavic Rivers a net seaward movement of the surface brackish layer and inward movement of the deeper saline water can be expected.

Low pool. When the emptying gates are open the water level in the low pool will drop at a rate only slightly less than the corresponding present ebbing tide rate. Therefore, during this period, velocities in Cobscook Bay can be expected to be similar to the present values. The flow in Lubec Narrows will, of course, be reversed from the present conditions, flooding southward and ebbing northward. During the 9 hr that the emptying gates are closed, the water level will rise 8 ft on the average. The water will spread in both directions below the powerhouse, i.e., towards the head and mouth of Cobscook Bay. Mean speeds in Cobscook Bay, west of the powerhouse, will be reduced to approximately one-third the present values. In the outer part of Cobscook Bay, below the powerhouse, the direction of flow will be reversed and speeds reduced on the average to approximately one-fifth their present values. The vertical–longitudinal, non-tidal circulation in Cobscook Bay, west of the powerhouse, is expected to consist of a seaward-moving thin-surface layer and an inward-moving sub-surface layer. Between the powerhouse and the emptying gates (Lubec Channel excepted) the flow will be unidirectional, moving with varying speeds toward the emptying gates.

Outside. During periods that the emptying and filling gates are closed (6 of 12½ hr) the only significant movement inside the Head Harbour–Bliss Island line will be that required to produce the local tidal prism. The 6 hr is

divided into two periods (Fig. 5): the first one of approximately 3½ hr during the rising tide, starting shortly after half-tide, and the second one on the falling tide, of 2½ hours duration, from just after high water to about half-tide. The flow during these periods, therefore, will be small and inward on the flooding tide and small but outward on the ebbing tide.

During the period the filling gates are open (approximately 3 hr) water will enter Passamaquoddy Bay at speeds only slightly less than at present, and will be in roughly the same proportion as in Letite and Little Letite Passages, and Western Passage (Trites and MacGregor, MS, 1959). Therefore the flow in the offing of Letite Passage will be similar to the present. However, there is no flow directly into the low-pool area from outside. Of the water entering Head Harbour Passage on the flooding tide, at present approximately 60% moves into Western Passage and the remaining 40% fills a volume equal to the intertidal volume of the low pool. Velocities in Head Harbour Passage will be reduced to approximately 50% of their present values, whereas along the Deer Island shore and between Indian Island and Deer Island velocities should be increased moderately due to the reduced cross-sectional area. The area covered inside the high pool by the water that has entered the filling gates per tidal cycle was computed on the bases that it occupied the entire depth, the upper 30 ft, and the upper 15 ft (Fig. 15). The minimal boundary is given by including the entire depth, while the 15-ft layer is considered to represent the maximal boundary. A similar construction was made for the water leaving the emptying gates. It is noted that even the boundary of the 15-ft layer does not extend to the Letite Passage filling gates. Bearing in mind the volume requirements of the Western filling gates, it is considered that under normal conditions only a relatively small proportion of water entering the Letite Passage filling gates will be recirculated water, whereas a relatively large proportion will be recirculated through the Western Passage filling gates. Wind speed and direction, however, may at times alter the normal situation significantly.

While the emptying gates are open, water flow speeds outside near the gates will decrease downstream. Except in the immediate vicinity of the gates, speeds are expected to be substantially reduced from the present values in the area.

In evaluating the probable effects on tidal flow outside the Bliss Island–Head Harbour line it is instructive to consider the present tidal streams and controlling factors for the entire Bay of Fundy. The energy involved in producing the tides in the Bay of Fundy is transmitted into the bay from the Gulf of Maine. It has been deduced by McLellan (1958) that 30.9×10^6 kw of power are transmitted into the Bay of Fundy, and of this, approximately 4% is transmitted into Passamaquoddy Bay. According to McLellan, the bulk of the energy (approximately 90%) is dissipated by friction and escapes from the Bay of Fundy in the form of heat. From the analysis of Ippen and Harleman (MS,1958) it was concluded that the Bay of Fundy, which could be represented as a damped co-oscillating system, is not highly resonant and that the effect of relatively minor disturbances, such as that of the proposed power project, on the primary tidal wave would be relatively minor.

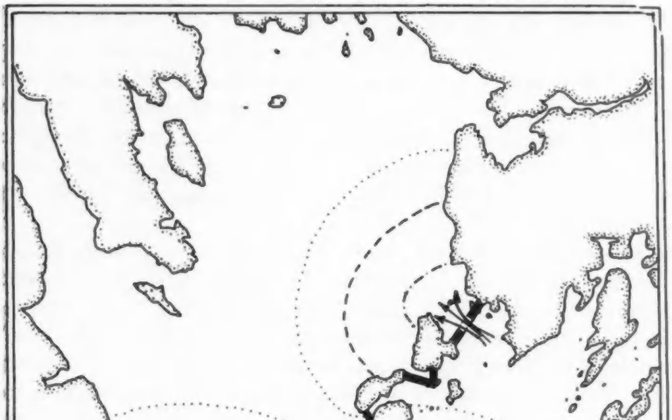

FIG. 15. Area covered by water entering the high pool and leaving the low pool per tidal cycle, assuming it occupied the entire depth, a 30-ft layer, and a 15-ft layer.

The analysis of the Bay of Fundy tidal system reveals no evidence that the partial closing off of Passamaquoddy Bay and Cobscook Bay will interfere significantly with the basic tidal conditions that exists in the Bay of Fundy. Therefore, the same quantity of energy should be transmitted into the Bay of Fundy after the installation of dams as at present. Since the flow into Passamaquoddy Bay and Cobscook Bay will be reduced to approximately 15% of the present value, there will be an excess of energy oustide. This will result in an estimated 1% increase in tidal range in the Bay of Fundy. The maximum increase in range should occur at the head of this bay, where McLellan (1958) computed the expected increase to be 0.7 ft. These changes are roughly equal to the changes predicted by Hachey (1934a) on the basis of complete closing of Passamaquoddy Bay.

In the outer Quoddy Region, while the change in tidal range is expected to be insignificant, the change in the tidal streams may be altered measurably. To facilitate a prediction in this regard, use was made of current measurement data (Forrester, 1960) taken in the Quoddy Region. The region was divided into a number of smaller areas whose boundaries were placed so that current measurements could be applied to compute the total flow of water into and out of each sub-area during a flooding tide (Fig. 16). The analysis revealed that for a flooding tide, of the total volume of water (68×10^{10} ft^3) moving through Grand Manan Channel, a quantity equal to only 31% is required for the intertidal volume in the Quoddy Region (Fig. 16). A volume equal to the remainder, 47×10^{10} ft^3, pushes out through the boundary between Grand Manan and Point Lepreau.

Compared to the water moving through Grand Manan Channel, a quantity less than 10% of the total is required to produce the tidal rise in Passamaquoddy and Cobscook Bays. Under the proposed conditions, this quantity will be decreased to less than 2%. While it is unlikely that the redistribution of energy throughout the cross-section across the Bay of Fundy from the Maine coast through Grand Manan Channel to Nova Scotia will occur uniformly, no reliable way was found to proportion it.

Assuming that the above-mentioned decrease of 8% in volume of water required for the impounded areas was transmitted entirely through Grand Manan Channel, the maximum decrease in the transport through the Channel would be 6×10^{10} ft^3 per flooding tide. To determine the maximum effect likely to be encountered in other areas, it is necessary to choose the upper limit for flow through Grand Manan Channel. It was assumed, therefore, that there would be no change in flow through Grand Manan Channel, and furthermore there would be no change in tidal streams along the Grand Manan shoreline. It is also assumed that the effect of impoundment increases in proportion to distance, reaching a maximum along the Head Harbour–Bliss Island line. The results of these calculations indicate that an increased tidal transport of approximately 10% between Grand Manan and The Wolves, and a decrease of about 20% between The Wolves and Campobello Island, can be expected. The transport into the passages will be decreased to approximately 25% of present

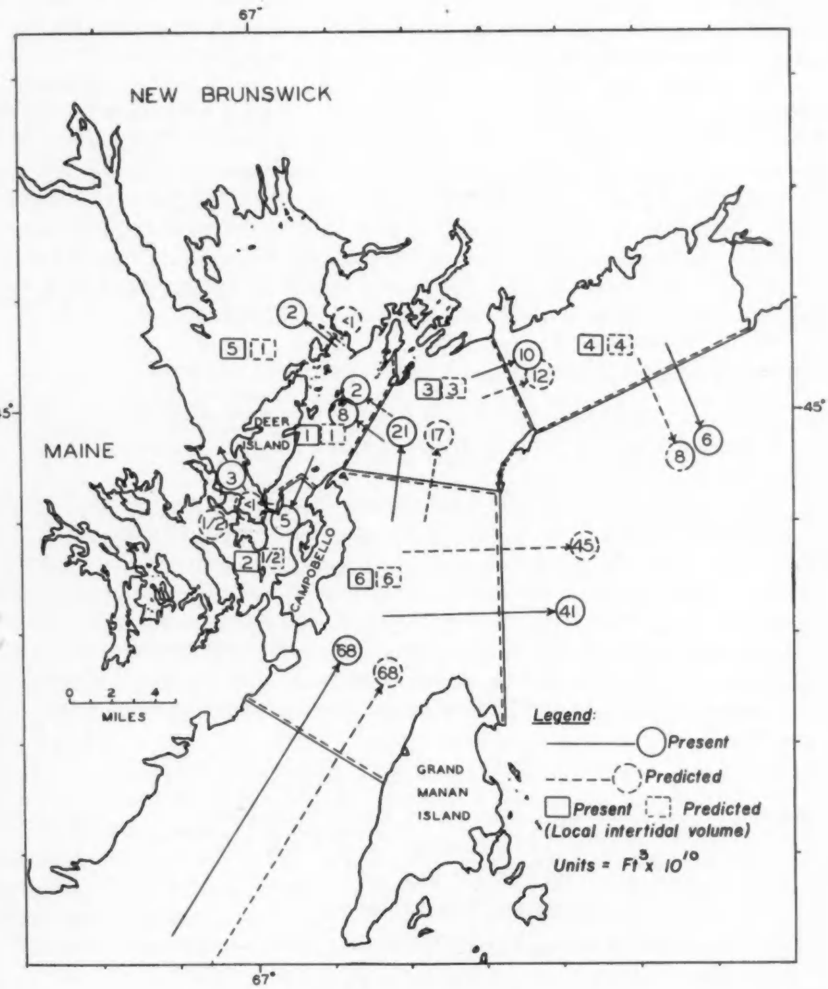

FIG. 16 Volume transports per flooding tide through various sections in the Quoddy Region for present and predicted conditions.

values. Between The Wolves and Beaver Harbour, and The Wolves and Point Lepreau, an increase of 20 and 30% respectively can be expected. Attention is drawn to two points. Firstly, the above computations represent the maximum changes anticipated; secondly, a change of 30% in the flow between The Wolves and Point Lepreau, although relatively large, requires a mean change in speed through the section of only 0.06 ft/sec.

The residual flow in the outer Quoddy Region appears to vary markedly in magnitude, direction and time (Chevrier and Trites, 1960; Forrester, 1960). The wind appears to play an important part in surface movement. There is little evidence to suggest that the amount of mixed water produced in the passages plays any significant role in the circulation away from the passages. Watson (1936) computed the amount of mixing produced by the Quoddy passages and concluded that it amounted to about 6% of the total mixing in the Bay of Fundy. He also concluded that the reduction in this amount of mixing would have very little effect on the general circulation in the Bay of Fundy.

TEMPERATURE AND SALINITY.

GENERAL. Reduced velocities will result in decreased vertical mixing, giving rise to increased vertical stratification and hence to greater seasonal variations in the surface waters.

Certain conclusions as to the mean changes in salinity in the two pools can be derived from a consideration of a simplified model of the new conditions. If it is assumed (a) that the water entering the Letite filling gates is "new" water, (b) that the water entering the Western filling gates is water that has been through the system one or more times, (c) that mixing of the water in each pool is complete both vertically and laterally, and (d) that motion is uniform from top to bottom, then, under steady-state conditions, the principle of conservation of salt enables an expression for the salinity (S_e) of the water leaving the system to be written as:

$$S_e = \frac{V_L}{V_L + R_P + R_C} S_L$$

where V_L = volume of water entering the Letite filling gates,
S_L = salinity of water entering the Letite filling gates,
R_P = fresh water entering the high pool,
R_C = fresh water entering the low pool;

and for the salinity of the high pool (S_p) by:

$$S_p = \frac{V_w S_e + V_L S_L}{V_t}$$

where V_w = volume entering the Western filling gates,
V_t = volume passing through the turbines.

By substitution of the appropriate values for the above quantities, S_e and S_p can be computed under different discharge conditions.

Predicted values of mean salinity have been drawn up (Table II) for conditions of normal river runoff and under maximum seasonal discharge conditions. For comparison purposes, the present values are also shown. In all cases the reduction in salinity under the impounded conditions is small. Maximum lowering, computed on this basis, is in Cobscook Bay and was found to be approximately 3‰, under freshet conditions.

TABLE II. Present and predicted (from salt balance equations) mean salinities (‰), for Passamaquoddy Bay, Cobscook Bay, and outside area, for normal and maximum fresh water discharge conditions.

Fresh water discharge	Passamaquoddy Bay		Cobscook Bay		Outside	
	Present	Predicted	Present	Predicted	Present	Predicted
	‰	‰	‰	‰	‰	‰
Normal	31.43	30.9	31.80	31.0	32.20	32.2
Maximum	30.82	28.7	31.28	28.5	31.72	31.7

HIGH POOL. Moderately marked lateral variation in the surface layer of the high pool is expected. The seasonal variations will be minimal near the Letite filling gates and maximal along the northern shore of Passamaquoddy Bay, in sheltered coves, and in the St. Croix and Magaguadavic estuaries.

From previous considerations, it appears that most of the water entering the Letite filling gates will be "new" water that has not been through the system recently, whereas the Western filling gates will transport a large proportion of recirculated water. Consequently, changes in temperature and salinity inside the Letite filling gates should be altered only slightly from present conditions. Maximum surface salinities should not exceed 30‰. Maximum surface temperatures should not exceed about 14°C. From a consideration of other areas, discussed previously, it appears that the mean monthly maximum temperature averaged over the entire surface layer for the high pool will be in the vicinity of 19°C. The maximum daily temperature for the surface layer in the high pool may reach a somewhat higher value, with about 20°C considered most probable. However, it will vary considerably from year to year, and with location within the high pool. Maximum temperatures can be expected to exceed 20°C in sheltered coves. The coincidence of neap tides, high air temperatures, high insolation, and low wind speeds, at about the time of occurrence of the maximum, could raise temperatures by several degrees in localized areas. The converse of the above combination would reduce the maximum markedly.

The average total fresh water discharge into Passamaquoddy Bay is approximately 4000 cfs of which 50% enters from the St. Croix River. A marked reduction of surface salinity in the St. Croix estuary above St. Andrews can be expected. Quantitative figures as to the extent of this reduction can be concluded only in the broadest terms. In a previous section, a British Columbia inlet was cited as an area somewhat similar to the St. Croix estuary. Although the St. Croix estuary is shorter than Loughborough Inlet, the discharge of fresh water

per unit area and per unit width can be considered comparable, and hence to a first degree of approximation the distribution of properties may be considered similar. In Loughborough Inlet the halocline is found at a depth of about 6 ft, and the mean salinity of the surface layer is 15‰. Salinity increases rapidly with distance towards the mouth. It is expected therefore, that in the area where Oak Bay and the St. Croix estuary join, and also in the vicinity of St. Andrews where the estuary widens abruptly, horizontal salinity gradients in the surface layer will be high. A similar situation can be expected near Midjik Bluff at the mouth of the Magaguadavic estuary.

The St. Croix estuary above St. Andrews, and the northern part of Passamaquoddy Bay are expected to have surface salinities less than 20‰ at most times. The salinity of the remainder of the high pool appears likely to fall within a 20 to 30‰ range. During freshet conditions, surface salinity will probably fall below 20‰ in the high pool, and to less than 10‰ in part of the St. Croix and Magaguadavic estuaries. It is doubtful if the depth of penetration of fresh water will exceed 30 to 50 ft, and it is probable that the bulk of it will be confined to the upper 5 to 15 ft.

Over the past 40 years, extreme ice cover has occurred in two winters. While these two winters represented unusual conditions, it appears that the region is one where, if the surface salinity and vertical mixing decreased substantially, ice formation would probably occur. It is concluded therefore that ice cover in the St. Croix estuary and northern part of Passamaquoddy Bay will occur normally. It is difficult to conclude how extensive this ice cover will be, or what its duration might be, but it appears evident that during particularly cold winters, or ones with heavy snowfall, ice cover will occur over most of the bay.

Salinities and temperatures of the deep layer in Passamaquoddy Bay will probably be altered only slightly with the expected range of temperature falling within 0° and 13°C. Bottom salinities, if altered, would appear to be within 1‰ of present values.

LOW POOL. All saline water reaching Cobscook Bay will be via the turbines and will carry with it the total fresh water discharged into Passamaquoddy Bay. Under present conditions the water in Cobscook Bay, which is in free communication with Western and Head Harbour Passage, is similar in properties to those found in these passages and therefore contains a portion of the fresh water discharged from the rivers draining into Passamaquoddy Bay. However, since this only represents a portion of the fresh water discharge, the mean salinity in the low pool should be lowered under the proposed plan. "Tidal" currents in the low pool will be somewhat higher than the corresponding ones in the high pool. This, combined with thorough mixing of water in passing through the turbines at any instant, will tend to reduce the vertical stratification more than in the high pool. Above Leighton Neck, however, a thin layer not more than some 3 ft thick may be quite brackish and its salinity at times will drop below 20‰.

Minimum bottom salinity which should occur some time after peak fresh water discharge conditions should not drop much below 28‰.

Since stratification is not expected to be as marked in the low pool as in the high pool, the mean range in temperature should be somewhat less. Surface summer maximum in the inner part of Cobscook Bay, however, may reach 20°C while the outer area is unlikely to be much greater than 15°C. Bottom water summer temperatures may increase by 2 or 3 C° due to its source being made up of a mixture of surface water from Passamaquoddy Bay and outside waters. Minimum bottom temperatures appear likely to be lowered only slightly from present conditions. In winter, ice cover can be expected to occur in the inner part of Cobscook Bay.

OUTSIDE. On the basis of previous computations there is little evidence for any pronounced change outside the Head Harbour–Bliss Island line. For the area inside this line, a somewhat greater seasonal variation can be expected, but this is unlikely to exceed a degree or two in temperature and a few parts per thousand in salinity.

Dissolved Oxygen

Under the present conditions, the water in the Quoddy Region is nearly saturated with oxygen at all depths due to the vigorous tidal mixing. Under the proposed conditions, mixing will be decreased inside the impounded bays, and it is probable that the oxygen concentration of the water in the deep basins in Passamaquoddy Bay and Cobscook Bay will be reduced. The rate of replacement of the deep waters, and hence the rate of supply of oxygen to the deep water within the basins, will be a minimum during periods of maximum fresh water discharge into the Quoddy Region. In Kennebecasis Bay, oxygen concentrations in the deep layer at times decreased to less than 40% saturation. It is concluded that, since the Kennebecasis represents a more extreme situation than Passamaquoddy Bay when dammed, oxygen concentration in the high pool is unlikely to fall below 50% saturation. There is no evidence to suggest that low-pool oxygen concentrations should drop below that of the high pool, or that any significant change should occur outside the impounded bays.

SUMMARY AND CONCLUSIONS

The proposed Passamaquoddy power project involves the construction of a series of dams across the mouth of Passamaquoddy and Cobscook Bays. Passamaquoddy Bay, the proposed high pool, will be filled near high water by 90 filling gates and Cobscook Bay, the proposed low pool, will be emptied near low water by 70 emptying gates. Water will flow continuously from the high pool to the low pool through a 30-turbine powerhouse.

The present oceanographic conditions in the region are summarized in broad terms in Table III. Although the general tides, circulation, and distribution

TABLE III. Approximate present oceanographic conditions.

			High pool	Low pool	Outside
Levels (feet)	Mean level (sea)		0	0	0
	Mean range		+10 ——20 −10	+9½ ——19 −9½	+9 ——18 −9
	Minimum–maximum elevation (spring range)		−14 to +14	−13 to +13	−13 to +13
Currents	Tidal (ft/sec)		<1 to 8	<1 to 8	<1 to 6
	Non-tidal (mi/day)*		Mostly <2	Mostly <2	Variable to 10
Temperature (°C)	Surface	Mean	7	7	7
		Range	0 to 14	0 to 13	1 to 12
	Deep	Mean	7	7	7
		Range	1 to 12	1 to 13	2 to 11
Salinity (‰)	Surface	Mean	31	32	32
		Range	24 to 32	29 to 33	30 to 33
	Deep	Mean	32	32	32
		Range	31 to 33	31 to 33	31 to 33

*1 nautical mi/day = 0.07 ft/sec.

TABLE IV. Probable oceanographic conditions after the dams are installed.

			High pool	Low pool	Outside
Levels (feet)	Mean level		+6	−5	0
	Mean range		4	8	18
	Minimum–maximum elevation		+3 to +11	−11 to 0	−13 to +13
Currents	Gates opened		As present	As present	As present
	Gates closed		Speeds markedly reduced; flow toward Western Passage	Speeds markedly reduced; flow spreads from turbines	Speeds markedly reduced in immediate area; slight increase further away
Temperature (°C)	Surface	Mean	Little change	Little change	Little change except in immediate area where somewhat greater seasonal variation will occur
		Range	<0 to 19	<0 to 16	
	Deep	Mean	Little change	Little change	
		Range	0 to 13	0 to 15	
Salinity (‰)	Surface	Mean	<25	≈25	
		Range	<20 to <30	<20 to ≈30	
	Deep	Range	29 to 33	28 to 32	

of properties have been described, only a qualitative evaluation of the relationship to the controlling factors has been possible. Without a quantitative relationship between the controlling factors and the circulation, etc., it is impossible to make precise predictions as to what will happen under a new set of controlling factors. In drawing conclusions as to the probable effect of the proposed power project on oceanographic conditions, considerable use has been made of the comparison technique, and hence it should be borne in mind that the predictions given are intended to place only the approximate limits on the changes anticipated. A summary of the gross effects and tendencies that can be expected in water levels, currents, temperatures and salinities in the high pool, low pool, and outside area is given in Table IV.

Water Levels

High pool. The mean level will be raised about 6 ft with "tidal" range averaging 4 ft. The minimum and maximum range will be $2\frac{1}{2}$ and $4\frac{1}{2}$ ft respectively. The minimum elevation which will occur during neap tides and the maximum elevation which will occur during spring tides will be 3 and 11 ft respectively above mean sea level.

Low pool. The mean level will be lowered 5 ft with a tidal range averaging 8 ft. The minimum and maximum range will be $5\frac{1}{2}$ and $9\frac{1}{2}$ ft respectively. The maximum elevation which will occur during mean tides and the minimum elevation which will occur during spring tides will be zero and −11 ft respectively relative to mean sea level.

Outside. The reduction of flow through the passages will result in a decrease in loading of the Bay of Fundy tidal system and hence give rise to a very slight increase in tidal amplitudes. The maximum range increase which is expected to occur at the head of the Bay of Fundy should be less than 1 ft. Little change is expected elsewhere.

Currents

High pool. For about $9\frac{1}{2}$ of $12\frac{1}{2}$ hr the filling gates will be closed. Water will leave the high pool continuously through the turbines and therefore the only motion will be towards Western Passage and will be contained mostly in the upper 45 ft. Mean speeds of the upper 45 ft are expected to be about one-fifth of the present values. It is expected that while the filling gates are open, speeds in most areas will be only slightly less than those under the corresponding present conditions. Somewhat higher speeds are likely to occur at mid-depths. A residual counter-clockwise circulation in Passamaquoddy Bay will likely be more marked than at present.

Low pool. When the emptying gates are open, velocities will be similar to present values at half ebb. For the remaining 9 hr the velocities should be less than one-third their present value in Cobscook Bay west of the powerhouse and approximately one-fifth between the powerhouse and Friar Roads. The

flow will spread in both directions from the low-pool side of the powerhouse. The vertical–longitudinal circulation in Cobscook Bay west of the powerhouse will be an inward movement of the deeper water and a seaward movement of the surface layer.

OUTSIDE. There is little indication that significant changes in residual flow will extend much beyond the Head Harbour–Bliss Island regions. Tidal streams are expected to be reduced in the approach area of the passages and increased in other areas of the Quoddy Region. The direction of the tidal stream will be altered only slightly while the changes in speed are unlikely to exceed 20% of their present value. For about 6 hr of the tidal cycle, velocities inside Head Harbour–Bliss Island will be very small. During the period the filling gates are open, flow in the Bliss Island region should be similar to the present but flow should be reduced in the Head Harbour region, and increased in the channel between Indian Island and Deer Island. Most of the water entering Western Passage filling gates will be water that has discharged from the low pool. The inflow through the Letite Passage filling gates will be mostly "new" water from outside the dams. The residual flow, which will be more marked than present, will be inward toward Letite and outward from Head Harbour Passage. Wind speed and direction can be expected to play an important role in controlling the amount of water recirculated through the Letite gates.

TEMPERATURE

HIGH POOL. Reduced currents will result in decreased vertical mixing giving rise to increased stratification and hence to greater seasonal variations in the surface waters. These variations will be a minimum near the Letite filling gates (altered only slightly from present conditions) and a maximum along the northern shore of Passamaquoddy Bay and in the St. Croix estuary. Summer maximum at the surface is likely to be in the vicinity of 20°C and winter minimum less than 0°C. Maximum depth of the surface layer would appear to be about 30 to 50 ft and probably only some 5 to 15 ft at most times. Temperatures in the deep layer will likely be altered only slightly with the expected range falling within 0° and 13°C. Ice cover is expected to occur over part of the bay in the winter.

LOW POOL. Stratification will not be as marked as in Passamaquoddy Bay except in the upper reaches. Surface summer maximum in the inner part of the bay may reach 20°C. In the outer area, it is unlikely to exceed about 15°C. Bottom water summer temperatures may increase by 2 to 3 C°; winter minimum temperatures will likely be lowered only slightly. In winter, ice cover is expected to occur in the inner part of the bay.

OUTSIDE. Little change is expected in the area contiguous to the emptying and filling gates and contained mostly inside the Head Harbour–Bliss Island line where a somewhat greater seasonal variation is anticipated.

Salinity

High pool. Mean surface salinity will be lowered. Bottom salinities are expected to be altered only slightly. During freshet conditions surface salinity appears likely to drop below 20‰. At other times of the year surface salinity except in the St. Croix estuary above St. Andrews and the northern part of the bay appears likely to fall within the 20 to 30‰. Maximum surface salinity should occur just inside the Letite filling gates and exceed 30‰. It is doubtful if the depth of penetration of fresh water will exceed 30 to 50 ft; the bulk of it will probably be confined to the upper 5 to 15 ft.

Low pool. All saline water reaching Cobscook Bay will be via the turbines and will carry with it the total fresh water discharged into Passamaquoddy Bay. The mean salinity should therefore be lowered. The maximum amount of this lowering (excluding peak runoff periods) should not exceed 3 to 4‰ (i.e., salinity not less than 28‰). It appears unlikely that the bottom salinity will drop below 28‰. Except for the upper reaches of Cobscook Bay, stratification should not be very marked. Above Leighton Neck however, a thin layer, probably not more than a few feet thick, may be quite brackish with salinity at times becoming less than 20‰.

Outside. The only significant change would appear to be in the area near the emptying and filling gates and inside the Head Harbour–Bliss Island line. Reduction in salinity is unlikely to exceed a few parts per thousand.

Dissolved Oxygen

Under present conditions the water in the Quoddy Region is nearly saturated with oxygen due to the vigorous tidal mixing. Under the proposed conditions mixing will be decreased inside the impounded bays and it is probable that the oxygen concentration of the water in the deep basins in Passamaquoddy Bay and Cobscook Bay will be reduced. The rate of replacement and hence the rate of supply of oxygen to the deep water within the basins will be at a minimum during periods of maximum fresh water discharge into the Quoddy Region. However, by comparison to Kennebecasis Bay which is considered to represent more extreme conditions than will be found in the high pool, it is concluded that the dissolved oxygen concentration is unlikely to fall below 50% saturation.

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Competition for Food Between Redside Shiners (*Richardsonius balteatus*) and Rainbow Trout (*Salmo gairdneri*) in Two British Columbia Lakes[1,2]

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ABSTRACT

The distribution, movements, behaviour and food of trout and shiners in Paul and Pinantan Lakes were studied to determine the items and mechanisms of interspecific competition between them. Data from recent years were compared with data for years when trout alone inhabited the lakes.

No interspecific aggression was observed. The possibility that the two species were competing for space was discounted. Stomach contents of shiners in Pinantan Lake revealed a marked qualitative diurnal food cycle. In Paul Lake, shiners have drastically reduced the *Gammarus* population relative to its pre-shiner abundance, forcing trout, as well as the shiners themselves, to shift their diets to other foods. This overgrazing was caused by the concentration of large numbers of shiners over the shoals where *Gammarus* are also present in their highest concentrations, and the ability of shiners to pursue food deeper into the weeds and to graze an area more thoroughly than trout. In Pinantan Lake, shiners have apparently reduced the density of *Daphnia* to a point where trout are unable to feed on them as rapidly as in pre-shiner years. The ability of both species to utilize many types of food tends to reduce the intensity of competition.

The study demonstrates how false implications may arise from an appraisal of competition not initiated until after the effects of competition have been observed. If observations had not been made on Paul Lake until after competition had been observed, the importance of *Gammarus* as an item of competition would probably have been overlooked and the whole competitive relationship misconstrued.

Environmental factors and behaviour were shown to be important influences on the dynamics of competition. The physical and biological environment and the distribution and behaviour of competitors may be in states of continual flux in which case the niches of the competitors cannot be considered constant.

INTRODUCTION

Field studies of interspecific competition are usually carried out in situations where two or more species have been in association for some time prior to the study period. In consequence there is often no opportunity to observe the sequence

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of events which transpired in the early stages of the interaction between the two species. The long-term studies on Paul Lake, British Columbia (Mottley, 1932; Rawson, 1934; Larkin *et al.*, 1950; Larkin and Smith, 1954; Crossman and Larkin, 1959; Crossman, 1959a,b) provide a good background for the present observations on the competitive relationship between the redside shiner (*Richardsonius balteatus*) and the rainbow trout (*Salmo gairdneri*).

The trout of Paul Lake and of Pinantan Lake (which is next above Paul Lake in the chain) were the only species of fish in the system before 1930. Sometime thereafter, redside shiners were introduced into Pinantan, and in the period 1945 to 1950 they were carried downstream into Paul Lake. There are at least three aspects to the interaction between the two species of fish: predation of shiners on trout fry, competition between shiners and juvenile trout for environmental resources, and predation by large trout on shiners. The present study was directed to an assessment of where, when, how, and for what environmental resources shiners compete with young trout.

A marked decrease from 1946 to 1957 in the growth rate and survival of Paul Lake trout less than 20 cm fork length leaves little doubt that the presence of shiners had adverse effects on young trout (Larkin and Smith, 1954; Crossman and Larkin, 1959). The same is apparently true in Pinantan Lake, although no observations were made there in "pre-shiner" years. Among trout below 20 cm fork length an unusually slow growth rate, similar to that observed in Paul Lake after shiners had become established, was found in Pinantan Lake in 1952 (MacLeod, MS, 1957) and during the present investigation in 1958—the only two years of observation. It seems reasonable to infer that shiners had adverse effects upon trout in Pinantan Lake similar to those observed in Paul Lake.

The field work on which this study is based was carried on at Paul and Pinantan Lakes during the summer of 1958. All of the field records and collected material are at the Institute of Fisheries at the University of British Columbia.

CHARACTERISTICS OF THE LAKES

The two lakes have some important limnological differences although they share a common climate and are adjacent in the drainage system. Some of the limnological characteristics are listed in Table I. Both lakes have one major inlet and a single surface outlet. Rawson (1934) discussed the limnology of

TABLE I. Limnological characteristics of Paul and Pinantan lakes.

	Paul	Pinantan
Area	960 acres; 237 ha	161 acres; 40 ha
Shoreline development	5.50	3.89
Maximum depth	182 ft; 56 m	62 ft; 19 m
Mean depth	112 ft; 34 m	31 ft; 9.5 m
Dissolved electrolytes	216 ppm	238 ppm
Altitude	2500 ft; 760 m	2860 ft; 870 m

both lakes, concluding that Paul was typically oligotrophic but with relatively high productivity because of extensive shoal areas, and that Pinantan was a highly productive eutrophic lake.

The shoal areas of both lakes are well developed with extensive growths of *Chara*, *Myriophyllum*, *Potamogeton* and filamentous algae. These shoal areas harbor large populations of fish food organisms and contribute a major portion of the total bottom fauna of both lakes (Rawson, 1934; Larkin *et al.*, 1950). Although organisms are most abundant in shallower areas, there is a substantial bottom fauna to the greatest depths in Paul Lake. From 1934 to 1949 the amphipods *Gammarus* and *Hyalella* declined in abundance, in association with an increase in the trout population. From 1949 to 1958 there was a further five-fold decline in abundance of amphipods associated with the introduction of redside shiners. Rawson observed no bottom organisms below the thermocline in Pinantan Lake and attributed this absence to severe oxygen depletion. In 1959 visible organisms were completely absent from samples taken from Pinantan Lake at depths of only 8 and 10 feet (2.5 and 3.0 m) in both June and August. However, the abundance of organisms was high in the shoal areas, increasing in volume and variety to the shallowest inch.

The mat of *Chara* and algae was so dense near shore that sampling with an Ekman dredge was impractical. Samples comprising 2 litres of *Chara* were collected with a rake; 11 from June 10 to 13 and a further 11 from August 20 to 25. They indicated a predominance of Odonata and Gastropoda, with a large number of *Planaria* in the June samples (Table II). The total volume of

TABLE II. Mean percentage volume of bottom organisms in 2-litre samples of *Chara* from depths under 10 feet (3 m) in Pinantan Lake, June and August, 1958.

1958	Odonata larvae	Trichoptera larvae	Hirudinea	Gastropoda		*Hyalella*	*Planaria*
				Physa	*Planorbis*		
June	32.3	1.7	1.1	11.7	7.1	3.4	27.0
August	77.4	+	+	17.4	+	4.3	+

organisms in the June samples was 3 times as large as in August. As in Paul Lake in recent years, the amphipods were relatively scarce, *Gammarus* being entirely absent from the samples although present in the lake.

The predominant zooplankters in both Paul and Pinantan lakes are *Daphnia* and *Diaptomus*. In Pinantan Lake blooms of *Aphanizomenon* and *Anabaena* are common, and *Chaoborus* occurs in the plankton at night. Neither extensive blue-green algae blooms nor *Chaoborus* occur in Paul Lake.

Summarizing: although Paul and Pinantan lakes differ somewhat limnologically, the food resources for rainbow trout and redside shiners in both lakes are concentrated in the shoal areas and the plankton.

FOOD OF SHINERS

Crossman (1959a) has described the nocturnal offshore movements of shiners. Accordingly, sampling for shiners was conducted both near shore and off shore over 24-hour periods in Pinantan Lake. Two gillnets of ½-inch (13-mm) stretched mesh were set for 1-hour periods at intervals of 4 hours, one at the edge of the shoal area and the other approximately 100 yards (90 m) offshore. The stomach contents of 168 shiners caught in the nets between July 6 and September 6 were examined. Of these, 150 were taken in the period August 20 to 26. In preliminary observations, groups of shiners were held without food for various lengths of time before their stomachs were examined. Whereas 90% of the stomach contents from fish killed immediately on capture were identifiable, only 15.5% were identifiable after the fish were held foodless for an hour, and 3.7% after 2 hours. It was concluded that almost all food had been eaten within 2 hours before capture. Hence any diurnal change in food habits would easily be detected in the stomach contents of the fish sampled from 1-hour sets made at 4-hour intervals.

A marked diurnal change in foods was discovered. Figure 1 shows a shift in dominance from *Daphnia* to algae during the day and back to *Daphnia* at

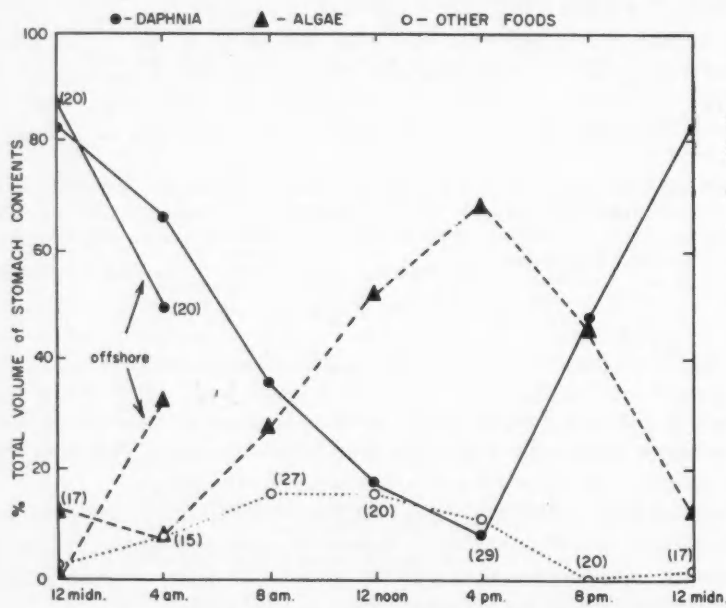

FIG. 1. Percentage total volume of *Daphnia*, algae and other foods in the stomach contents of shiners taken at 4-hour intervals over 24 hours. Unidentified food is not included among the "other foods". Numbers in brackets give sample sizes.

night in the diet of Pinantan Lake shiners. There was no significant diurnal variation in the quantity of food eaten. The stomachs of 37 shiners taken at midnight contained 92.5% *Daphnia* and 6.2% algae (mainly *Spirulina*, *Spirogyra* and *Nodularia*). In contrast the stomachs of 29 shiners taken at 4 p.m. contained only 19.1% *Daphnia* and 69% algae.

The shift is more striking for offshore fish than for those on the shoals. At midnight, 20 offshore fish had virtually no algae in their stomachs while 17 shoal fish had 14% algae, but by 4 a.m., 20 offshore fish had 34% algae in their stomachs while 15 shoal fish had only 8% algae. All shiners move back to the shoal at dawn; shiners were caught offshore only in the midnight and 4 a.m. sets.

Zooplankton, consisting almost entirely of *Daphnia pulex*, made up 58.1% of the diet and algae contributed 26.4%. Other food included *Hyalella*, various aquatic and terrestrial insects, *Planorbis* and *Physa*. None of these other foods ever contributed more than 12% of the diet of a group of fish caught at one time, and together they made up only 6.1% of the total diet. About 10% of the food was too well digested to be identified.

Stomachs of shiners collected in 1959 in Paul Lake by the writers and in various previous years in both lakes by members of the British Columbia Game Commission were also examined. The deterioration of all but the 1959 stomachs made accurate stomach analysis difficult. Apparently there was no marked qualitative diurnal variation in the feeding habits of Paul Lake shiners similar to that found in Pinantan shiners. Collections of 10 shiners taken at 2 p.m. and 2 a.m. on August 1, 1959, both contained approximately 15% *Gammarus* and 85% terrestrial insects. Terrestrial insects were also the main food of 20 shiners taken in Paul Lake on July 25, 1950.

No algae or *Daphnia* were found in the stomachs of any Paul Lake shiners taken between 1950 and 1959. This is in sharp contrast to Pinantan Lake where *Daphnia* and algae contributed over 85% of the total diet in 1958.

FOOD OF TROUT

The diet of trout in Paul Lake has been reported extensively by Rawson (1934), Larkin *et al.* (1950), Larkin and Smith (1954) and Crossman and Larkin (1959). Prior to the entrance of shiners into the lake, trout of all sizes shared a mixed diet of near-shore bottom organisms, plankton and terrestrial insects. From 1934 to the 1946–1949 period there was an increased utilization of plankton and a noticeable decline in the occurrence of amphipods, both trends being construed as evidence of heavier grazing of food resources by a larger trout population. After 1949, shiners became an increasingly important food item, largely replacing plankton in the diet of trout over 10 inches (25 cm) fork length. Smaller trout had diets similar to those of the pre-shiner period except for a notable decline in the proportion of stomachs containing amphipods (Fig. 2).

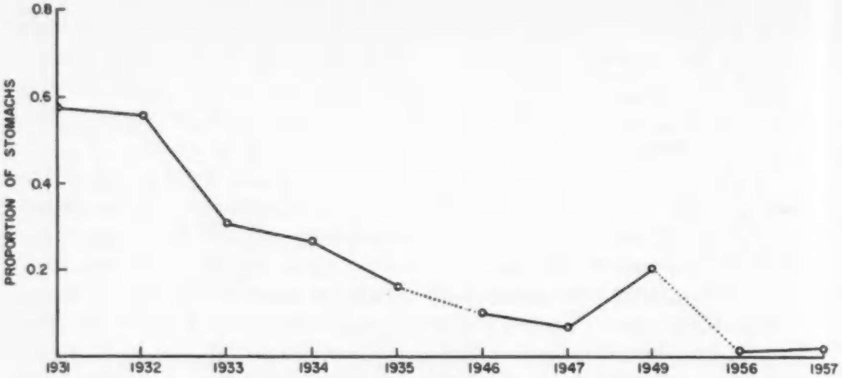

FIG. 2. Proportion of rainbow trout stomachs containing amphipods, Paul Lake, 1931 to 1957. (Extended from Larkin *et al.*, 1950.)

The stomach contents of 335 trout taken from Pinantan Lake in the summer of 1958 suggested a similar diet to that of Paul Lake trout in recent years (Table III). For fish under 10 inches, *Daphnia* made up over 60% of the diet throughout the July to September period. Bottom organisms (chiefly dragonfly nymphs and chironomids) were important in the remainder of the diet except for later in the season when terrestrial insects contributed substantially. Shiners contributed 70% of the diet of trout over 14 inches fork length, the remainder being bottom organisms and *Daphnia* which were more important as food sources late in the season. *Gammarus* and *Hyallela* were recorded in the stomach contents but were a negligible food item. The trout of intermediate size (10 to 14 inches) showed lower utilization of shiners and a greater dependence on *Daphnia*, a diet intermediate between those of smaller and larger sized trout.

Diaptomus was absent from the stomachs of both trout and shiners in both lakes despite the fact that it is a very abundant plankter in both lakes. The very low availability to salmonids of *Cyclops*, a similar copepod, has been mentioned by Southern (1933), Lindstrom (1955) and Nilsson (1955).

AREAS AND TIMES OF SPECIES OVERLAP

Crossman (1959a) described the seasonal and diurnal movements of shiners in Paul Lake. Their movements in Pinantan Lake were similar although the trends were not as clear-cut as those observed in Paul Lake.

Data on the distribution of shiners in Pinantan were derived from direct observations made day by day during June through August 1958, as well as from gillnet sets made just off the shoal and offshore.

The shiners first appear on the shoals in schools in May or June. Observations commenced on Pinantan Lake in the middle of June. The shiners on the shoal exhibited the same vertical and horizontal stratification noted by Crossman

TABLE III. Average volume of stomach contents of Pinantan Lake rainbow trout according to month and length-group in 1958. The number in brackets under each length group is the number of trout in that group for the whole year. The number in brackets beside the month is the number of trout of all sizes in that month.

a: number of stomachs containing each food item;
b: percentage of stomachs containing each item;
c: volume of each item as a percentage of the total volume of food.

Fork length		July (104)								August (162)								September (69)							
		Shiners	*Daphnia*	Anisoptera nymphs	Chironomid larvae	Other insect larvae	Other bottom organisms	Terrestrial insects	Miscellaneous	Shiners	*Daphnia*	Anisoptera nymphs	Chironomid larvae	Other insect larvae	Other bottom organisms	Terrestrial insects	Miscellaneous	Shiners	*Daphnia*	Anisoptera nymphs	Chironomid larvae	Other insect larvae	Other bottom organisms	Terrestrial insects	Miscellaneous
6–10 *in* 15–25 *cm* (122)	a	2	21	4	2	4	–	2	9	7	48	8	24	8	1	5	10	–	21	4	4	2	–	11	12
	b	6	69	11	6	11	–	6	25	13	86	14	43	14	2	9	18	–	70	13	13	7	–	37	40
	c	8	61	9	+	7	–	+	14	22	63	9	1	+	+	4	2	–	65	2	2	1	–	18	13
10–14 *in* 25–36 *cm* (116)	a	12	8	6	4	3	–	2	3	14	33	16	12	12	3	2	13	2	17	3	3	2	–	4	2
	b	40	27	20	13	10	–	7	10	23	54	26	20	20	5	3	21	8	68	12	12	8	–	16	8
	c	53	14	13	1	10	–	4	4	33	28	18	+	14	5	+	2	6	31	30	1	3	–	21	8
14+ *in* 36+ *cm* (97)	a	25	3	11	1	4	4	–	9	29	19	16	16	7	1	5	14	4	5	5	5	–	–	4	4
	b	65	8	29	3	10	10	–	24	64	42	36	36	16	4	11	31	29	36	50	36	–	–	29	29
	c	76	1	9	+	3	5	–	4	68	10	15	1	1	+	2	3	30	20	40	+	–	–	6	5

(1959a) in Paul Lake and Lindsey (1953) in Rosebud Lake: the smallest shiners were closest to the shore and the larger fish were progressively deeper and farther offshore. On cloudy days all but the newly hatched fry, ½ inch long, moved into deeper water just off the shoal. The shiners were most frequently seen in schools of from 30 to 500. Occasional individuals swimming lethargically by themselves were observed throughout the summer. Dead shiners were also seen frequently. Presumably some disease was affecting these fish, although it was not identified. Incidence of the tapeworm *Ligula*, which varies from almost 100% to almost zero in various years, was negligible in 1958.

In early July the vertical stratification for all but the fry broke down gradually. The largest fish left the shoals first. An estimated 50% of the fry remained on the shoal during this general offshore movement.

By the end of August the schools had reformed and stratified on the shoals again. The lake was treated with toxaphene in early September. Presumably the fish would have moved offshore en masse in October as they had been observed to do in previous years by the lodge owner and by Crossman (1959a) in Paul Lake. Nothing is known of their winter distribution. Local residents report that they collect around holes cut in the ice during the winter.

Previously described around-the-clock gillnetting showed that, similarly to Crossman's findings in Paul Lake, the shiners in Pinantan Lake spread out over the surface waters of the lake as nightfall approached, and moved back to shore at the first light of morning. During the night they were caught from the surface down to a depth of 25 feet (7.6 m).

At 11:30 p.m., June 25, about 1/20 of the daytime numbers were seen by flashlight on the shoal, randomly distributed according to size horizontally and vertically, except for fry which were still in schools within 6 inches (15 cm) of the surface.

There is a considerable background of information on movements and distribution of trout in Paul Lake. Tagging studies done in 1952 and reported by Crossman (1959b) indicated that "at least in 1952, there were no discrete populations of trout at any one place at any one time" (except during the spawning migration) in Paul Lake. "The trout seemed to move about freely from place to place over the length of the lake, at times moving from one end to the other."

Observations and results of gillnetting on both Paul and Pinantan Lakes indicate that during the summer the large trout, 10 inches (25 cm) and larger, tend to stay around and below the thermocline. Mottley and Mottley (1932) stated that the older fish in Paul Lake "seek great depths" during the summer. By contrast, recently planted hatchery fingerlings (2–5 inches, 5–13 cm) were seen in large numbers on the shoals in as little as a foot (30 cm) of water in July 1959, often swimming in company with schools of shiners.

The only area where trout and shiners were both observed in numbers during the summer was on, or just off, the shoals in the upper 20 feet (6 m) of water. Trout, but not shiners, also ranged below this depth. No trout were ever taken along with shiners in the offshore gillnet sets. Competition for food thus seems

to be centred mainly around the shoals between shiners and young trout. However, co-occupancy of an area is not a prerequisite for competition if the items competed for are mobile. Considerations discussed in a later section suggest that the offshore night grazing by shiners in Pinantan Lake may be another component of competition, acting to reduce the numbers of zooplankters which might move towards the shoals or into deeper water where they would become available to trout.

Shiners occupy the shoal areas from July to September, making excursions offshore at night, on cloudy days and for a short period in July. The remainder of the year they are apparently predominantly offshore where they, like the trout, are believed to be relatively inactive, and little competition for food probably occurs.

COMPETITION FOR FOOD

a. Paul Lake

The abundance of the amphipods, *Gammarus* and *Hyallela*, is a conspicuous feature of most of the small lakes of the Kamloops district in British Columbia. The decline in their abundance, first in response to increased grazing by trout, and then further after the introduction of redside shiners, has been a noticeable feature of the Paul Lake studies. Figure 2 indicates the decline in occurrence of these amphipods in trout stomachs from 1931 to 1957. Mottley and Mottley (1932) reported that in 1931 trout stomachs contained an average of 167 amphipods, and Rawson (1934) indicated that they contributed 39.8% of the total volume of the food eaten. In the 1946 to 1949 period, amphipods contributed only 9.4% of the food of trout (Larkin *et al.*, 1950), and from 1955 to 1957 even individual gammarids were rarely present in the stomachs of trout (Crossman and Larkin, 1959).

Pen feeding experiments, with *Gammarus* collected from nearby Louis Lake, were carried out to observe the feeding behaviour of trout and shiners on this apparently highly vulnerable food organism. In each pen 500 *Gammarus* were released and given adequate opportunity to seek shelter in a quantity of *Chara* which had been washed previously to remove all visible organisms. In a 24-hour period 10 trout from 3 to 6 inches (7.6–15 cm) long, reduced the initial number of *Gammarus* to 119; 10 shiners from 1½ to 3 inches (3.8–7.6 cm) long reduced the initial number to 105, while 315 *Gammarus* were recovered from a control pen containing no fish. There is thus little doubt that each species found *Gammarus* acceptable as food. The *Gammarus* left by the shiners averaged 3 times as large as those left by trout.

The possibility of physical interaction between trout and shiners during their co-exploitation of *Gammarus* was examined. Field observations suggest that interspecific aggression does not occur between the two species. Crossman (MS, 1957) observed no aggressive activity and commented that the shiners "appeared to be more efficient feeders and when a trout and shiner darted after the same food item, the shiner invariably got it and while shiners would move

right into the shore to feed, trout appeared to come only into water no shallower than 15 inches".

In the course of the 1958 and 1959 summer observations many trout 3 to 5 inches (76–127 mm) long were seen swimming in company with, or in and out of, schools of shiners in 2 to 8 feet (0.6–2.5 m) of water. There appeared to be no interspecific behavioural activity; each species apparently being oblivious to the other. Shiners, however, moved noticeably faster and hence ranged over a wider area per unit time in search of food than trout.

Shiners 1–3 inches long (25–76 mm) and trout of 3–6 inches (76–152 mm) were held in enclosures for observation and feeding experiments. Four-sided pens, 6 × 6 × 5 feet deep (2 × 2 × 1.6 m), built of door screen on a wooden frame, were placed on *Chara* beds near shore and anchored firmly to the bottom in about 4 feet (1.2 m) of water. The bottoms of the pens were open, hence the enclosed fish were swimming over natural *Chara* beds and had access to the bottom. There was no observed difference in the behaviour of the two species when together and when alone. Trout remained singly at the sides or corners of the pen just above or down among the dense weed growth, except when they were feeding. Shiners stayed in compact groups in a volume of about 8 cubic feet (0.24 m^3) just above and among the tips of the weeds. Only when frightened by quick movements of the observer did they scatter down into the weeds. The school moved very slowly over the whole area of the pen, often staying more or less in one spot for 10 minutes or more, but never seeming to favour any spot nearer the sides or corners any more than the centre of the pen. Figure 3 illustrates the characteristic disposition of the two species of fish when they were not feeding in the enclosures.

Figure 4 illustrates the characteristic arrangement of the individuals of the two species when given food. Approximately 2000 *Gammarus*, most of which were alive, were placed in pens already containing trout and shiners. These observations were repeated four times during July and August 1958 with virtually identical results.

The shiners, being at first higher above the weeds, were on the whole faster to notice the *Gammarus* and faster to start feeding than the trout. When the trout started feeding they ranged higher above the weeds than the shiners and the shiners ranged deeper into the weeds than the trout. Trout seemed to take *Gammarus* "at random", making erratic rushes here and there, often ignoring amphipods close by and rushing after others farther away. Shiners appeared to feed more efficiently and methodically than trout. They moved as a school eating every *Gammarus* near them that was visible to the observer as well as making feeding movements at objects too small for the observer to see. (This was not so with the trout. The observer could invariably see the objects on which they were feeding). The shiners fed more slowly than the trout, making approximately half the number of feeding movements per individual per unit time as did the trout. They often spat out and rejected larger *Gammarus*.

Trout often chased and nipped each other during the feeding period but were never observed to chase or nip shiners. Occasionally a trout and shiner would

collide while moving in search of food. As the trout were larger and moving faster, the shiners were usually pushed aside in this collision. However, incidents of this nature appeared accidental and were infrequent. On one occasion only one 2-inch shiner chased a 4-inch trout for about one foot horizontally.

On some occasions small trout spat out large *Gammarus* three or four times before finally swallowing them or rejecting them completely. On some such occasions a shiner would eat the amphipod before the trout had a chance to mouth it again. This was the only type of overt competition for the same food item which was observed.

It has been stated that trout would not forage down among the weeds in search of food as the shiners did. A second line of evidence in Paul Lake supports this observation. *Gammarus* were abundant down to a depth of 50 metres in pre-shiner years of low trout abundance (Rawson, 1934). When the trout population was increased as a result of heavy stocking, *Gammarus* below the *Chara* zone decreased markedly in abundance while in the *Chara* zone they decreased only slightly (Larkin *et al.*, 1950). *Chara* appears to provide amphipods with relatively effective shelter from the predation of trout.

Attempts to estimate the size of the population of shiners in Paul Lake have not met with much success. All who have attempted population estimation have agreed that the shiner population was extremely large in both Paul and Pinantan. Lindsey (1953) found the numbers of shiners in Paul Lake too great for accurate estimation with practical fin clipping experiments, but stated that in 1950 the number was somewhere between 5 million and 100 million. Larkin and Smith (1954) estimated the number in 1952 as "several million". At the same time the trout population was recruited from hatchery plantings of 200,000 fry per year, augmented by natural spawning (Larkin *et al.*, 1950). The population of trout over 6 inches (15 cm) fork length was in the range of 15,000 to 20,000. Even estimating the population of small trout generously as 200,000, the shiners were perhaps 50 times as abundant as young trout. The numerical preponderance of shiners was apparent from direct observation on the shoal areas in the midsummer. Schools of several thousand were common.

The grazing potential of this population of shiners, their readiness to eat amphipods, and their concentration over the shoal areas strongly suggest that they were capable of substantial inroads on food resources previously exploited only by trout.

b. Pinantan Lake

In Pinantan Lake the shiner population was also obviously very much larger than the population of small trout. There were relatively few amphipods compared with Paul Lake when shiners were introduced, according to Rawson (1934). He attributed this to the absence of an extensive *Chara* zone in Pinantan[5].

[5]Since this time a very rich and extensive *Chara* zone has developed in Pinantan Lake. As this plant affords amphipods considerable protection from the predation of trout it is probable that a large amphipod population would have developed along with the *Chara* had shiners not been present to graze them down.

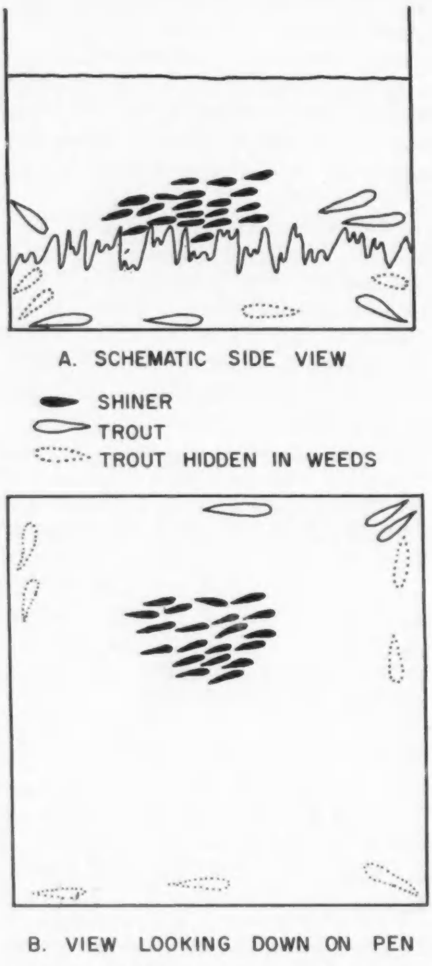

FIG. 3. Diagram of the distribution of trout and shiners in the observation pens when not feeding.

Trout remain at the sides or corners of the pen just above or down among the weeds. Shiners hover in a compact school above and among the weed tips, favouring neither centre nor sides of the pen.

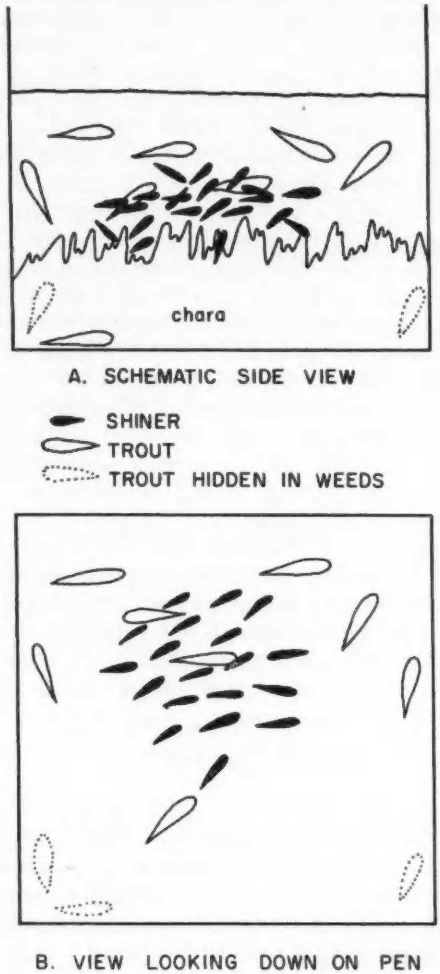

FIG. 4. Diagram of the distribution of trout and shiners in the observation pens when feeding. Trout range higher in the water than shiners. Shiners go deeper into the weeds for food than trout. (Trout pictured in the weeds have just returned from feeding excursion and do not feed while in the weeds.) Shiners still school though less compactly than when not feeding. Trout do not school. The two species intermingle as though oblivious to each other.

There were still very few amphipods in the lake during the study period and *Daphnia* was the main item of food of both shiners and young trout.

It is impossible to determine the effects of the shiners on the abundance of *Daphnia* in Pinantan Lake directly, as there are no data from pre-shiner years. However, their probable effects may be inferred from a comparison of the present situation with one described by Ricker (1937) where competition among sockeye salmon fingerlings for *Daphnia* resulted in significantly reduced growth rates in years of large salmon populations.

Direct observations of the densities of shiners on the shoals in both Paul and Pinantan Lakes suggest that their concentrations in the two lakes were approximately the same. The concentrations of shiners present at night in the pelagic feeding ground in Paul Lake vary between 1 and 18 per 6 cubic metres (calculated using data from Lindsey, 1953). This approximates the concentration of sockeye in Cultus Lake in August 1932 noted by Ricker (2 in 7 m^3).

In August, 1958, adult shiners in Pinantan Lake consumed about 2200 *Daphnia* per day[6]—4.5 times as many per individual as the sockeye in Cultus Lake as estimated by Ricker. The concentration of *Daphnia* in Pinantan Lake was about 1.2 per litre—less than half the concentration observed in Cultus Lake, although the turnover rate of plankton may be higher in eutrophic Pinantan Lake than in oligotrophic Cultus Lake.

Intraspecific competition for *Daphnia* occurred at the described levels of food, feeders and feeding in Cultus Lake. Since the food requirements of young rainbow trout and sockeye fingerlings are similar, the above comparison suggests competition for *Daphnia* between shiners and young trout in Pinantan Lake. This may account for the observation that the growth rate of young Pinantan trout was even slower than the shiner-retarded growth rate of young Paul Lake trout.

SUMMARY OF RESULTS

Interspecific aggressive behaviour was not a factor in competition for food between trout and shiners at Paul and Pinantan Lakes. No chasing or nipping was observed either in the lakes or in the observation pens.

Shiners in Pinantan Lake had a marked qualitative diurnal food cycle.

Five observations suggest that trout are at a disadvantage when competing with shiners for amphipods in Paul Lake:

1. Shiner's range deeper among the weeds in search of food than trout, cropping off many bottom organisms before they reach areas above the weeds where they are available to trout.
2. Shiners eat food items smaller than the smallest items taken by trout, grazing off many amphipods before they reach a size at which they are

[6]This estimate is based on the previously described digestion rate experiments, volumetric stomach analysis, and a count of the number of *Daphnia* per cubic centimetre of pure *Daphnia* in a trout stomach. Stomach contents of trout, rather than shiners, were used for the last figure because the pharyngeal teeth of shiners fragment their food so much that the enumeration of individual plankters is impossible.

available to trout. Shiners graze heavily on immature amphipods, presumably leaving fewer to survive long enough to reproduce and replenish the population.

3. In the summer during the day, shiners are concentrated directly over the shoals. Trout tend also to be near the shoals, but farther offshore and in deeper water, not so close to the main source of amphipods.
4. Shiners feed more methodically than trout, searching areas more thoroughly for their food.
5. There are probably 50 or more shiners for each trout in the lake.

The competition for *Daphnia* in Pinantan Lake is not as readily studied and described as the competition for amphipods in Paul Lake. Several facts are apparent however. Shiners feed on *Daphnia* in the upper pelagic region during the night. Trout do not occupy this area. It is suggested, however, that the grazing of shiners is sufficiently intense that the amount of zooplankton moving into deeper water or into shoal areas, where it becomes available to young trout, is reduced significantly.

DISCUSSION

Competition in nature is usually first recognized only after its results have become apparent. Usually a noticeable change in one of the competing populations (e.g. reduction, extinction, emigration) must occur before the observer becomes aware that competition is taking place. At this time one cannot pick out the features of the competitors' biology that differ from those existing before competition began. Discovering the items and mechanisms of competition under these circumstances is like trying to discover the plot of a novel from the last chapter.

The present situation in Paul Lake serves to illustrate how false conclusions may be drawn from a delayed appraisal of competition. In recent years amphipods have been scarce in the lake, and have formed only a small fraction of the stomach contents of trout and shiners. On the basis of this observation alone an observer would hardly suspect that amphipods had been the most important item of competition. What is more, as there is relatively little overlap in the present feeding habits of the two species, one might conclude that competition for food was negligible. The present situation is an example of Hartley's (1948) statement that "the finding of different foods in different species is not irrefutable proof of the absence of competition, unless it can be shown that all selection of foods is by choice alone from diverse superabundant food stocks all equally accessible to the species studied". Observations made before and during the first phase of competition showed that shiners and trout were not feeding by choice alone. They had been forced by the depletion of amphipods to replace them by other, presumably less preferred foods.

This shift in the diets of trout and shiners in Paul Lake since competition began serves to caution against assuming that the present feeding habits of the two species in Pinantan Lake tell the whole story of competition there. Possibly the most important original items and mechanisms of competition in Pinantan were quite different from what they were at the time of this study.

It is possible that if the other foods in Paul Lake were reduced by shiners to a level of abundance comparable to that in Pinantan Lake, the shiners would shift to *Daphnia* as their main food. A second phase of competition, paralleling that described in Pinantan Lake, might then ensue. Nilsson (1955) reports that char in Swedish lakes turn from a diet of bottom organisms to plankton when the former become scarce.

However the complex of environmental variables, which influences the intensity and the items of competition discourages prediction of future developments in either lake. An epizootic of unknown etiology resulted in a mass mortality of shiners in Paul Lake in August 1958. Subsequently, in 1959, shiners were found far less frequently in trout stomachs. Amphipods were significantly more abundant in the trout diet in 1959, presumably because there were fewer shiners to graze them down.

Infestation by the tapeworm, *Ligula*, in shiners varies from almost 100% to almost nil in the lakes from year to year. *Ligula* infested shiners are not only sluggish and more vulnerable to the predation of trout, but they also have extremely small amounts of food in their stomachs compared with uninfested fish. Individual shiners probably consumed significantly less food in years when they were heavily parasitized.

Yearly differences in rainfall and atmospheric temperature cause almost a two-fold difference in the summer heat income of Paul Lake (Larkin *et al.*, 1950). Fluctuations of this magnitude might be expected to result in significant year-to-year differences in food production, fish distribution and spawning success of trout and perhaps shiners—all of which are factors in the intensity of competition. Nilsson (1955) has ascribed year-to-year differences in the foods of trout and char in three Swedish lakes to the effect of differences in temperature and lake levels in different years, at least in part. In the space of any one year seasonal changes in temperature and oxygen profiles, light and precipitation, and diurnal changes in light, combine to complicate further the dynamics of competition. Year-to-year, seasonal, or diurnal changes occur in: rate of food production; relative abundance of various types of food; accessibility of food (e.g. *Gammarus* are probably less vulnerable to predation by trout and shiners in years and seasons of highest *Chara* growth); reproductive rates of competitors; density of competitors in relation to the density of food; distribution of competitors with respect to each other and with respect to food; size distribution of competitors (relevant because of the propensities of different size groups for different foods). Both competitors and items of competition are thus non-randomly distributed in both space and time in a highly complicated fashion.

Larkin (1956) has commented on the vague demarcation of ecological zones in freshwater environments and the lack of sharp demarcation of fish faunas

within these zones. "Freshwater communities would seem to be characterized by more breadth than height in the pyramid of a food chain; a complexity in horizontal organization." A better illustration of this statement[7] than the present one could hardly be imagined. Both shiners and trout eat almost all the organisms available in the lakes—including each other. At different times of the day, and of the year, fish may be found leading a pelagic, shoal, or bottom existence, with their food habits varying accordingly. The feeding habits of trout and shiners in various lakes described in the literature reveal an enormous range of dietary tolerance. The ability of both species to change their distributions and diets tends to reduce intensity of competition. While amphipods have been severely depleted in Paul Lake, both trout and shiners have found substitutes for them in their diets. That this new diet is not as satisfactory as the old one for young trout may be inferred from their slower growth rate—but large trout now grow faster than before as a result of feeding on shiners. Hence the difference in abilities of large and small trout to change their diets results in opposite effects of competition within different size groups of the same species.

To summarize, interspecific competition among fishes may be continually shifting in intensity and emphasis. The physical and biological environment and the distribution and behaviour of the competitors may be in states of continual flux, in which case the niches of the competitors cannot be considered constant.

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Herring Movements in the Bay of Fundy and Gulf of Maine, 1957 and 1958[1,2]

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ABSTRACT

During 1957 and 1958, 137,469 herring were tagged in the southern part of the Bay of Fundy and the western part of the Gulf of Maine. These fish were immature and ranged in mean total length from 9.9 to 20.0 cm and in age from 1 to 3 years. Recovery of 3,582 (2.6%) tagged individuals showed that herring moved in and out of Passamaquoddy Bay irregularly throughout the summer and autumn with some tendency to concentrate at the head of this bay. Outward movement reached a peak in July when there was a considerable movement eastward towards Point Lepreau. Herring moved into Passamaquoddy from as far south as Grand Manan and from as far east as Point Lepreau. Little interchange of herring took place between the Passamaquoddy area and the coasts of Maine and Nova Scotia. The greatest straight-line distance from release to recovery points was 55 miles. More than half of the recaptures were made within 2 miles of the tagging sites and nearly two-thirds within 5 miles. About 28% of the recaptures were made within 1 week after tagging and 63% within 2 weeks. The average time before recapture was 12 days in 1957 and 17 days in 1958. The longest time between release and recapture for both years was 165 days. Drift bottles released with tagged herring showed no apparent relationship between herring movements and surface drift. The results of tagging support a general conclusion that the proposed Passamaquoddy tidal power structures will have no significant effect on the herring fisheries of the Passamaquoddy area.

INTRODUCTION

In the Passamaquoddy area of southwestern New Brunswick and eastern Maine, there is a large fishery for young, immature herring "sardines". In 1958 landings in Charlotte County, New Brunswick, and Washington County, Maine, were approximately 68,000,000 lb or nearly 25% of the total herring landings in the Bay of Fundy and Gulf of Maine for that year. Catches are used chiefly for the production of canned sardines. Fish meal and oil, pet food and bait are other products.

To provide details of young herring movements, tagging experiments were carried out in 1957 for the first time along the Atlantic coast of North America as part of the International Passamaquoddy Fisheries Board research program (Hart and McKernan, 1960). These experiments were continued in 1958. Major responsibility for the project was assumed by the Fisheries Research Board of Canada and 49 of 59 tagging experiments in the two years were conducted from the St. Andrews Biological Station. The Boothbay Harbor laboratory of the United States Bureau of Commercial Fisheries carried out 10 taggings and assisted in 20 others.

Reports on the 1957 experiments were published by McKenzie and Tibbo (1958) and McKenzie and Skud (1958). The present paper gives the results of the 1958 experiments and discusses herring movements in both years in relation to distance, time and direction.

[1]Received for publication, September 28, 1960.
[2]International Passamaquoddy Fisheries Board, 1956–59. Scientific Report No. 30.

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MATERIALS AND METHODS

An opercular tag (Fig. 1) developed for smelt by McKenzie (1950) was used for all herring taggings in both 1957 and 1958. Tags were made of various shapes to identify different taggings. Experiments were conducted to determine the colour that would yield the best returns. On June 17, 1958, 220 scarlet and 250 maroon tags were attached to dead fish entering Connors Bros. sardine plant at Black's Harbour, N.B. Returns of 165 (75%) scarlet and 128 (51%) maroon tags showed that scarlet was a better colour to use. A further experiment was carried out using live fish from a weir at Navy Island near St. Andrews, N.B., on July 25, 1958, when 968 "sardines" were tagged with scarlet tags, 986 with maroon tags and 964 with yellow tags. Returns of 13 (1.3%) scarlet, 0 (0.0%) maroon, and 6 (0.6%) yellow, again showed scarlet to be the best colour to use. The 1958 tagging operations (Table I) give returns of 1,278 (4.5%) scarlet, 1,506 (2.2%) maroon and 6 (0.2%) yellow tags.

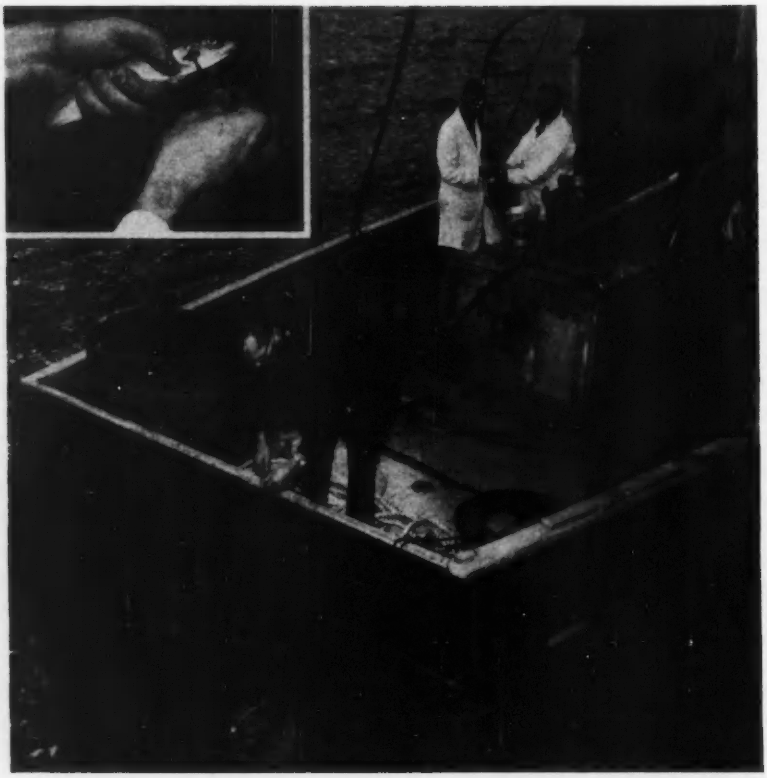

FIG. 1. Tagging method and equipment. Type of tag and point of attachment shown in inset.

TABLE I. Recaptures from herring taggings, March 3 to October 17, 1958. (S = Scarlet tag, M = Maroon tag, Y = Yellow tag).

Location	Fish tagged		Recaptures		Total recaptures	
	Date	Number	Complete data	Incomplete data	Number	Percentage
Long Island Bay, N.B.	Mar. 3	1951(M)	7	0	7	0.4
Red Head Harbour, N.B.	Mar. 11	1965(S)	54	1	55	2.8
East Wolf Island, N.B.	Mar. 18	2966 (S M)	143	0	143	4.9
Seely Cove, N.B.	Mar. 20	1913(S)	10	0	10	0.5
Maces Bay, N.B.	Apr. 9	1913(M)	4	0	4	0.2
Crow Cove, N.B.	Apr. 10	971(M)	1	0	1	0.1
Fox Island, N.B.	May 2	2863(S)	43	1	44	1.5
Loring Cove, Me.	May 9	2970(M)	234	0	234	7.9
Birch Cove, N.B.	May 16	2974(S)	708	6	714	24.0
Little Kennebec, Hope Is., Me.	May 16	2992(M)	41	2	43	1.4
Mascarene Shore, N.B.	May 22	2479(S)	91	5	96	3.9
St. Andrews Point, N.B.	May 29	2956(S)	144	5	149	5.0
New River Island, N.B.	June 4	1937(S)	14	0	14	0.7
Bean Island, N.B.	June 10	1889(S)	67	3	70	3.7
Mill Cove, N.B.	June 17	1399(M)	180	6	186	13.3
Moose River Cove, Me.	June 17	2959(M)	30	2	32	1.1
Bean Island, N.B.	June 19	2960(M)	112	18	130	4.4
Griffin Cove, N.S.	June 24	2405(M)	3	0	3	0.1
Sandy Cove, N.S.	June 25	1126(M)	0	0	0	0.0
Spider Cove, N.B.	July 2	2984(M)	335	27	362	12.1
St. Andrews Point, N.B.	July 3	2945(M)	31	1	32	1.1
Bocabec Bay, N.B.	July 4	2993(M)	112	23	135	4.5
Chandler Bay, Me.	July 8	1480(M)	0	1	1	0.1
Sprucehead Island, Me.	July 9	1970(M)	1	0	1	0.1
East Bay, Me.	July 10	2976(M)	63	0	63	2.1
Great Chebeague Island, Me.	July 11	2104(M)	1	0	1	0.04
Linekin Bay, Me.	July 17	2933(M)	1	0	1	0.03
St. Andrews Point, N.B.	July 25	2918(S M Y)	19	0	19	0.7
Dipper Harbour, N.B.	July 31	2959(S)	19	0	19	0.6
New River Beach, N.B.	Aug. 1	2970(M)	59	0	59	2.0
Eagle Island, N.B.	Aug. 6	1472(M)	2	0	2	0.1
Cedar and Laireys Is., Me.	Aug. 19	2128(M)	0	0	0	0.0
Seely Cove, N.B.	Aug. 20	2531(M)	11	0	11	0.4
Sprucehead Island, Me.	Aug. 20	2949(M)	1	0	1	0.03
Gleason Cove, Me.	Aug. 26	2623(M)	44	0	44	1.6
McCann Cove, N.B.	Aug. 29	2951(S)	24	0	24	0.8
Holt Point, N.B.	Sept. 4	1494(M)	23	0	23	1.5
Passamaquoddy Bay, N.B.	Sept. 5	2982(M)	50	1	51	1.7
Long Pond Bay, N.B.	Sept. 23	1460(Y)	0	0	0	0.0
Two Island Harbour, N.B.	Sept. 24	1460(S)	3	0	3	0.2
Lobster Cove, Me.	Oct. 15	2169(M)	2	0	2	0.09
Capitol Island, Me.	Oct. 17	2935(M)	1	0	1	0.03
Sub-totals:						
Scarlet tags		28,308	1,257	21	1,278	4.5
Maroon tags		69,242	1,425	81	1,506	2.2
Yellow tags		2,424	6	0	6	0.2
Totals		99,974	2,688	102	2,790	2.8

The herring tagged in 1958 were obtained from weirs and seines as in 1957. During most of the taggings, samples from the same catches were taken for length and age analyses. Samples taken within the Passamaquoddy area in 1958 varied in mean total length (calculated on the basis of 10 mm groupings) from 9.9 to 19.8 cm and in age from 1 to 3 years. The overall mean length for all 1958 samples was 14.1 cm (15.6 cm in 1957). Table II shows the size range and mean length of each sample obtained. There was no indication that size variation influenced the tagging results. Figures 3 to 11 illustrate the results of representa-

TABLE II. Size distribution of herring tagged in 1958.

Date	Locality	Size range	Mean length
		cm	*cm*
Mar. 3	Long Island Bay, N.B.	8–17	12.4
Mar. 11	Red Head Harbour, N.B.	7–16	11.4
Mar. 18	East Wolf Island, N.B.	9–17	13.3
Mar. 20	Seely Cove, N.B.	8–19	12.3
Apr. 9	Maces Bay, N.B.	8–16	11.6
Apr. 10	Crow Cove, N.B.	7–16	9.9
May 2	Fox Island, N.B.	9–21	12.5
May 9	Loring Cove, Me.	9–18	13.1
May 16	Birch Cove, N.B.	10–20	15.1
May 16	Little Kennebec, Me.	9–14	10.9
May 22	Mascarene Shore, N.B.	9–19	12.7
June 4	New River Island, N.B.	8–16	9.9
June 10	Bean Island, N.B.	10–21	14.0
June 19	Bean Island, N.B.	11–20	14.0
July 2	Spider Cove, N.B.	12–20	15.7
July 3	St. Andrews Point, N.B.	11–26	16.2
July 4	Bocabec Bay, N.B.	11–20	15.0
July 8	Chandler Bay, Me.	12–20	14.1
July 9	Sprucehead Island, Me.	14–20	16.8
July 10	East Bay, Me.	14–24	16.8
July 11	Great Chebeague Is., Me.	9–25	17.9
July 17	Linekin Bay, Me.	13–19	15.9
July 25	St. Andrews Point, N.B.	12–20	15.2
Aug. 1	New River Beach, N.B.	11–28	15.8
Aug. 19	Cedar & Laireys Is., Me.	9–22	18.0
Aug. 20	Seely Cove, N.B.	15–28	19.8
Aug. 20	Sprucehead Is., Me.	14–23	17.5
Sept. 4	Holt Point, N.B.	15–25	18.7
Sept. 5	Passamaquoddy Bay, N.B.	15–24	18.3
Oct. 15	Lobster Cove, Me.	9–18	12.1
Oct. 17	Capitol Island, Me.	9–17	13.4

tive taggings in 1957 and 1958. Only recaptures with complete information are shown in the figures or considered in the text. Distances from tagging sites to recovery positions were measured in straight lines.

TAGGING AND RECAPTURES, 1958

Table I shows that from March to October 1958, 99,974 "sardine" herring were tagged in 39 locations (Fig. 2) on 42 occasions. Sixteen locations were

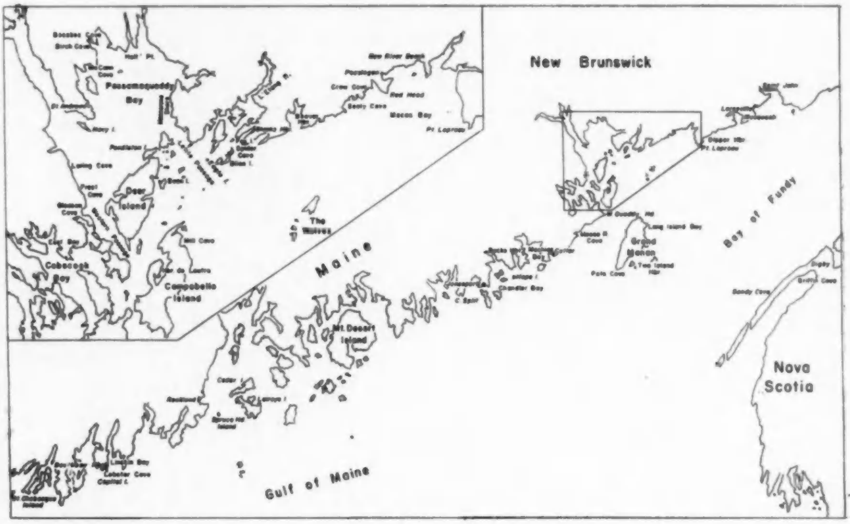

FIG. 2. Map showing location of tagging sites and other places mentioned in the report.

in or at the mouth of Passamaquoddy Bay, 10 were located westward along the coast of Maine as far as Great Chebeague Island, 8 were eastward along the New Brunswick shore as far as Dipper Harbour, 3 were off Grand Manan and 2 off Digby Neck, Nova Scotia. A total of 2,790 (2.8%) tags were recovered, 2,688 with complete data concerning time and place of recapture.

LONG ISLAND BAY TAGGING

On March 3, 1,951 purse-seined herring were tagged at Lat. 44°44′27″N, Long. 66°43′05″W. Of the 7 recaptures, 4 were made in the tagging locality within 2 days. The other 3 were recaptured 3 weeks later on May 24 near Red Head on the mainland, 20 to 25 miles northeast of the tagging location.

Red Head Harbour Tagging

On March 11, 1,965 purse-seined herring were tagged at Lat. 45°05′22″N, Long. 66°35′19″W. Forty-four of the 54 recaptures were made within 2 miles of the tagging site and distributed fairly evenly over a 5-week period. No recaptures were made more than 10 miles from the tagging site. Twenty-two recaptures were made at the tagging site. Five recaptures were made eastward in the Pocologan region; 26 westward, chiefly in Seely Cove and Beaver Harbour and 1 at The Wolves Islands.

East Wolf Island Tagging (Fig. 3)

On March 18, 2,966 herring were tagged from a shut-off seine in Southern Cove on East Wolf Island. Out of a total of 143 recaptures, 90 were made at the tagging site—52 from April 7–9; 33 on April 19; 3 on April 24; and 2 on May 8. Forty-eight recaptures were made along the mainland shore from Dipper Harbour to Bliss Island, chiefly within the first 9 weeks, though 2 recaptures were made 18 weeks after tagging. Four recaptures 9 weeks after tagging and 1 recapture 12 weeks after tagging were made at the head of Passamaquoddy Bay.

Seely Cove Tagging

On March 20, herring were obtained in Seely Cove from a purse seiner and 1,913 were tagged and released at the mouth of this Cove (Lat. 45°05′15″ N, Long. 66°38′15″ W). Ten recaptures were made; 3 in the first week, 3 in the third, 3 in the fifth, and 1 in the sixth. Only 1 was recaptured within 2 miles of the tagging site, 6 were retaken 2 to 6 miles eastward along the shore and 2 about the same distance westward. One was recaught offshore at The Wolves Islands about 7 miles away on April 24.

Maces Bay Tagging

On April 9, herring were obtained in Maces Bay just west of Point Lepreau from a purse seiner and 1,913 were tagged and released at Lat. 45°07′10″ N, Long. 66°29′42″ W. Only 4 tags were recovered, 3 within 2 miles of the tagging site (2 on April 15 and 1 on April 19) and 1 (on May 20) in Bocabec Bay at the head of the Passamaquoddy Bay, 23 miles away.

Crow Cove Tagging

On April 10, 971 purse-seined herring were tagged and released at Lat. 45°06′06″ N, Long. 66°36′44″ W. The single recovery from this tagging was made on July 7, 13 weeks after tagging, at Mill Cove, Campobello, 15 to 16 miles away.

Fox Island Tagging (Fig. 4)

On May 2, 2,863 herring were tagged at Fox Island weir. The 43 recaptures were spread over a 12-week period. During the first week 11 recaptures

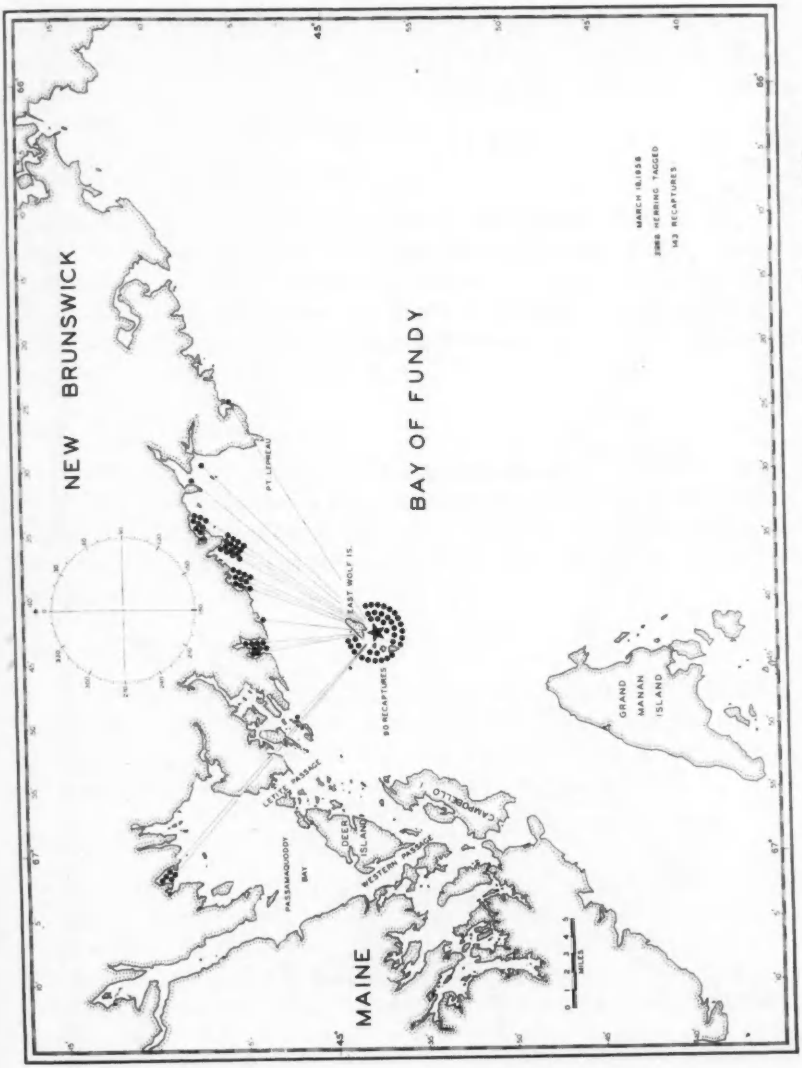

FIG. 3. Recaptures from herring tagged at East Wolf Island, N.B., on March 18, 1958.

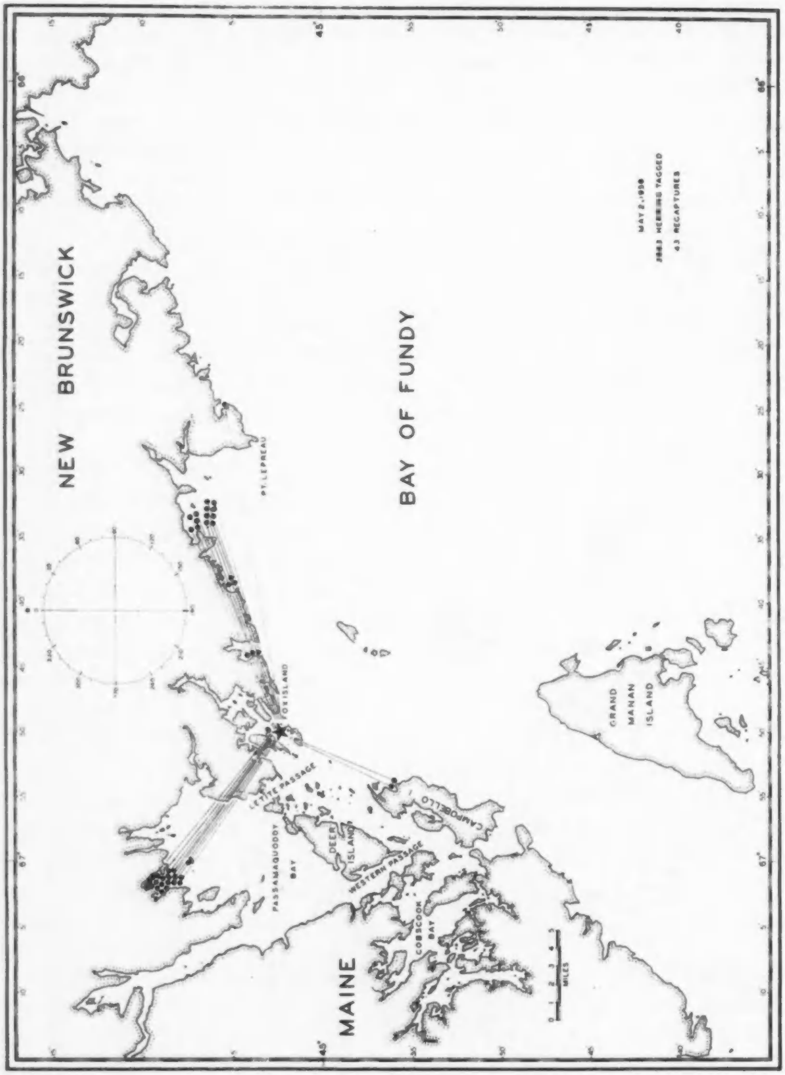

FIG. 4. Recaptures from herring tagged at Fox Island, N.B., on May 2, 1958.

were made; 3 in Beaver Harbour, 3 off Seely Head and 5 off Pocologan. There were no recaptures during the second week. During the third week, 4 were retaken at Pocologan and 7 in Bocabec Bay. The recaptures in the fourth to twelfth weeks were made in the same general areas as those made earlier except for 1 at Dipper Harbour and 2 off Campobello. In all, 20 were recaptured eastward to Dipper Harbour, 20 northward in Passamaquoddy Bay, 2 westward to Campobello and 1 at the tagging site.

Loring Cove Tagging (Fig. 5)

On May 9, 2,970 herring were tagged from George Johnson's weir in Loring Cove. None were recovered in United States waters or within 2 miles of the tagging site. All 234 recaptures were made in a 19-week period following tagging. Most (227) of the recaptures were made at the head of Passamaquoddy Bay. One was recaptured at Seely Cove, 4 near Pocologan, 1 at Mill Cove, Campobello, and 1 off eastern Grand Manan.

Birch Cove Tagging (Fig. 6)

On May 16, 2,974 herring were tagged and released at the Miller weir in Birch Cove. Of the 708 recaptures over 20 weeks, 631 were made within 2 miles of the tagging site and 51 from 2 to 5 miles away. Only 8 recoveries were made outside Passamaquoddy Bay. The others (18) were made near the entrances to the bay and just inside.

Hope Island Tagging

On May 16, 2,992 herring were tagged and released off Hope Island, Little Kennebec, Maine, about 25 miles southwest of Passamaquoddy Bay. Of the 41 recaptures, 9 were taken the first week and 32 the second week after tagging. All were recaptured within 2 miles of the tagging site.

Mascarene Shore Tagging (Fig. 7)

On May 22, 2,479 herring were tagged and released from the Mascarene weir on the east side of Passamaquoddy Bay. Recoveries were made over a period of 16 weeks. As at Loring Cove on the west side of Passamaquoddy Bay no recaptures were made within 2 miles of the tagging site. Also, the pattern of recaptures was similar in that 81 of the 91 recaptures were made at the head of Passamaquoddy Bay. Seven recaptures were made in other parts of the bay, 1 outside near the northeast end of Campobello Island and 2 eastward as far as New River Beach.

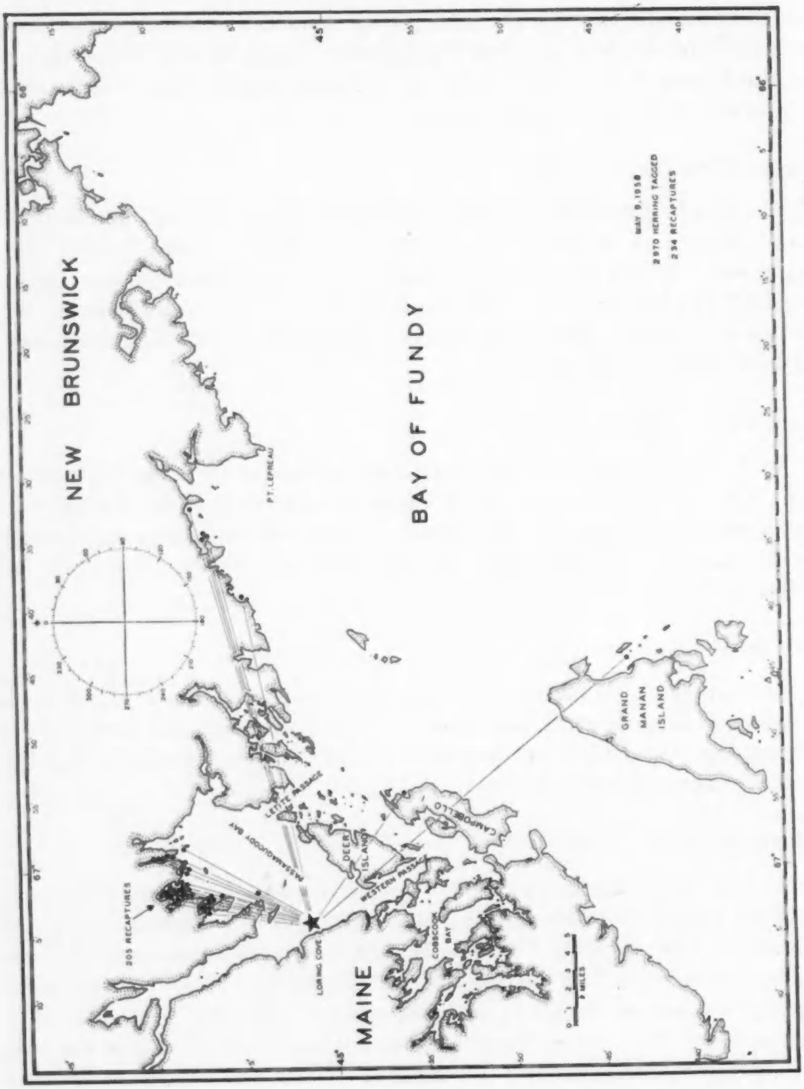

FIG. 5. Recaptures from herring tagged at Loring Cove, Maine, on May 9, 1958.

FIG. 6. Recaptures from herring tagged at Birch Cove, N.B., on May 16, 1958.

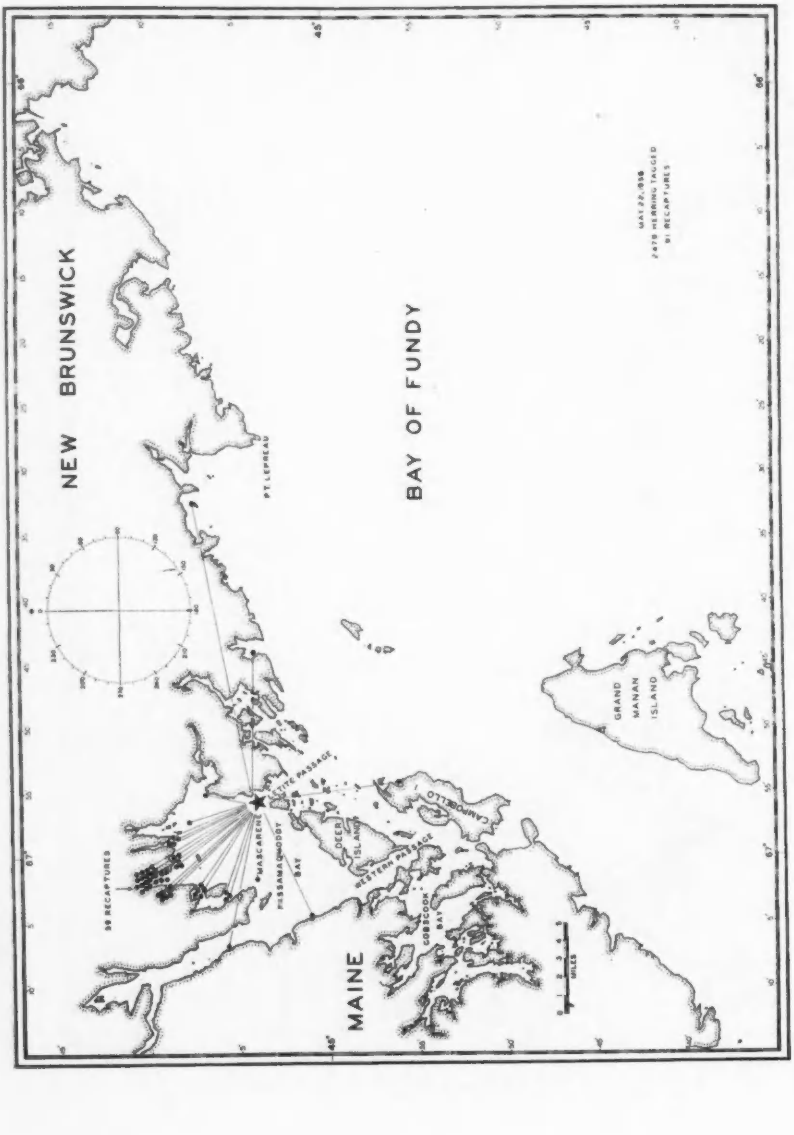

FIG. 7. Recaptures from herring tagged at Mascarene Shore, N.B., on May 22, 1958.

St. Andrews Point Tagging

On May 29, 2,956 herring were tagged and released from the Protection weir. Of the 144 recoveries in 24 weeks 127 were made at the head of Passamaquoddy Bay. Four recaptures were made at the tagging site, 10 among the islands at the mouth of this bay, and 3 near Pocologan. In general, recoveries were similar to those for the Loring Cove and Mascarene Shore taggings.

New River Island Tagging

On June 4, 1,937 herring were tagged and released from the Bartlett weir off New River Island just west of Point Lepreau. Fourteen recaptures were made over an 8-week period. Eleven of these were recovered within 2 miles of the tagging site, 1 near Saint John about 20 miles eastward, and 2 about 20 miles westward—1 in Bocabec Bay and the other in Mill Cove, Campobello.

Bean Island Tagging

On June 10, 1,889 herring were tagged and released from the Giller weir off Bean Island. Sixty-seven recaptures were made over a 21-week period following tagging. Here again most (47) of the tagged fish were taken at the head of Passamaquoddy Bay. Six recaptures were made at other points in the bay, 2 were recaught at the tagging site and 12 along the shore eastward towards Point Lepreau.

Mill Cove, Campobello, Tagging

On June 17, 1,399 herring were tagged and released from the Mill Cove weir on the eastern end of Campobello Island. Of the 180 recaptures within 12 weeks, 163 were made at the tagging site. Of the other 17 recaptures, 10 were made at various locations in the Passamaquoddy region, 6 eastward as far as Saint John and 1 off Digby Neck, Nova Scotia.

Moose River Cove Tagging (Fig. 8)

On June 17, 2,959 herring were tagged and released in the outer part of Moose River Cove about 8 miles west of West Quoddy Head. There were 30 recaptures altogether, 29 within 7 weeks and 1 during the twelfth week. One recapture was made at the tagging site and 1 just east of it. Westward there were 16 recaptures at Cutler, Maine, and 1 at Jonesport, Maine. Eastward there was 1 at Grand Manan, 2 in Passamaquoddy Bay and 8 along the New Brunswick shore from Letite Passage to Dipper Harbour.

FIG. 8. Recaptures from herring tagged at Moose River Cove, Maine, on June 17, 1958.

Bean Island Tagging

On June 9, 2,960 herring were tagged and released from the Giller weir located off Bean Island. Of the 112 recaptures over 21 weeks, only 17 were made at the tagging site. Most (82) of the recaptures were made in Passamaquoddy Bay. Of the remainder, 1 was retaken off the western end of Deer Island, 2 in Mill Cove, Campobello, and 10 along the shore from Letite to Musquash Harbour, just west of Saint John.

Griffins Cove Tagging

On June 24, 2,405 herring were tagged and released from the Sidney Westcott weir, Digby Neck, N.S. Only 3 recaptures were ever recorded from this tagging, 2 at the tagging site during the first week after tagging and 1 off Deer Island during the second week.

Spider Cove Tagging

On July 2, 2,984 herring were tagged and released from the Trial weir in Spider Cove, Bliss Island. The majority (319) of the 335 recaptures were made within 3 weeks of tagging, most (270) of them at the tagging site. The remaining 65 were retaken away from the tagging location in various directions, 49 eastward as far as Dipper Harbour, 9 southwestward to Mill Cove, Campobello, 6 northwestward to the head of Passamaquoddy Bay, and 1 northeastward into the Letang River estuary. No recoveries were made after the thirteenth week.

St. Andrews Point Tagging

On July 3, 2,945 herring were tagged and released from the Short Bar weir off St. Andrews Point. In general, the fish moved either northeastward towards the head of Passamaquoddy Bay (21 recoveries) or out of the bay eastward along the New Brunswick shore (7 recoveries). Three recaptures were made at other points in Passamaquoddy Bay. All recaptures were made within 10 weeks.

Bocabec Bay Tagging

On July 4, 2,993 herring were tagged and released from the Orr weir at the head of Bocabec or Big Bay. Of the 112 recaptures 102 were made in the first 4 weeks after tagging and 10 in the following 15 weeks. Eighty-nine recaptures were made close to the tagging site, 20 near the eastern entrance to Passamaquoddy Bay, 2 near the western entrance to this bay, and 1 near Point Lepreau.

Sprucehead Island Tagging

On July 9, 1,970 herring were tagged and released from the Harold Simmons' weir off Rockland, Maine. Only 1 recapture was ever recorded and that from the Simmon's weir on July 21.

East Bay Tagging

On July 10, 2,976 herring were tagged and released from the Tucker-Parker stop seine in Cobscook Bay, Maine. Sixty of the 63 recaptures were made within 3 weeks of tagging, and all within 9 weeks. Fifty-six recaptures were made near the tagging site, 1 at Little Machias Bay, 4 in other parts of Cobscook Bay, and 2 in Passamaquoddy Bay.

Great Chebeague Island Tagging

On July 11, 2,104 herring were tagged and released from Henry Dyer's stop seine off Great Chebeague Island, Casco Bay, near Portland, Maine. Only 1 was ever recorded as recaptured and that on July 16 at Little John Island off Yarmouth, Maine, about 2 to 3 miles from the tagging site.

Linekin Bay Tagging

On July 17, 2,933 herring were tagged and released from Brink Chapman's stop seine at the head of Linekin Bay, Boothbay Harbor, Maine. There was only 1 recorded recapture and that on July 21 in Linekin Bay.

St. Andrews Point Tagging

On July 25, 2,918 herring were tagged and released from the Navy Island weir. No recaptures were recorded during the first 3 weeks following tagging. There were 19 recaptures altogether, 14 of them within Passamaquoddy Bay. In addition, there was 1 recapture near the eastern and 2 near the western entrances to the bay, and 1 at Musquash near Saint John. The final record for this tagging was a recapture in the fifteenth week on the Nova Scotia side of the Bay of Fundy.

Dipper Harbour Tagging (Fig. 9)

On July 31, 2,959 herring were tagged and released from the Plumper weir at the entrance to Dipper Harbour. During the first week 15 of the 19 recaptures were recorded, 14 in Sand Cove near Saint John about 18 miles east of the tagging site, and 1 off Lorneville about 13 miles eastward. From 2 to 5 weeks later, 3 were recaught in Musquash Harbour and 1 in Sand Cove. No recoveries were made at the tagging site. All were made eastward towards Saint John. Fourteen of the tagged fish moved about 18 miles in 4 days.

New River Beach Tagging (Fig. 9)

On August 1, 2,970 herring were tagged and released from the Harvester weir at New River Beach. In the first week after tagging, 53 of the total of 59 recaptures were recorded, all within 2 miles of the tagging site. Two more were recaptured in the second and third weeks, both from the tagging area. During the sixth week, 3 were recovered at the head of Passamaquoddy Bay, almost 20

FIG. 9. Recaptures from herring tagged at Dipper Harbour, N.B., on July 31, 1958; New River Beach, N.B., on August 1, 1958.

miles in a straight line westward. The final recapture was made off Fairhaven at the west end of Deer Island on November 10, 15 weeks after tagging.

The majority of the recaptures were made near the tagging site. However, some were made to the westward, as shown by the recaptures at the head of Passamaquoddy Bay and off western Deer Island. This movement is in the opposite direction to that indicated by the Dipper Harbour tagging on the previous day.

Eagle Island Tagging

On August 6, 1,472 herring were tagged and released from the Eagle Island weir just outside and to the east of Letite Passage. Only 2 recaptures were recorded, 1 in the first week about a mile away from the tagging site and 1 six weeks after tagging at the head of Passamaquoddy Bay.

Seely Cove Tagging

On August 20, 2,531 herring were tagged and released from the Comet weir at the western entrance to Seely Cove. Of the 11 recaptures, 4 were made west (as far as Passamaquoddy Bay) of the tagging site, and 7 east (as far as Musquash Harbour) of it. In this tagging, unlike that at either Dipper Harbour or New River Beach, recaptures were made nearly 20 miles away both westward and eastward and all within 4 weeks.

Sprucehead Island Tagging

On August 20, 2,949 herring were tagged and released from the Edgar Post weir off Sprucehead Island, Maine. On August 26, the single recapture from this tagging was made within 2 miles of the tagging site.

Gleason Cove Tagging

On August 26, 2,623 herring were tagged and released from Edwin Evan's weir in Gleason Cove, Maine. There were 44 recaptures within 5 weeks, 1 at the tagging site, 5 along the Maine shore inside Passamaquoddy Bay, 5 off the north side of Deer Island, and 33 at the head of Passamaquoddy Bay.

McCann Cove Tagging

On August 29, 2,951 herring were tagged and released from the McCann Cove weir. All 24 recaptures were made inside Passamaquoddy Bay within 6 weeks after tagging.

Holt Point Tagging

On September 4, 1,494 herring were tagged and released from the Holt Point weir. All 23 recaptures were made at the head of Passamaquoddy Bay, 12 in the first week after tagging and 11 during the second week.

Passamaquoddy Bay Tagging

On September 5, 2,982 herring were tagged and released from purse-seine catches at Lat. 45°02′45″N, Long. 66°59′30″W in the deeper, open waters of Passamaquoddy Bay, about 1½ miles northwest of Pendleton Island. There were 50 recaptures, 23 within the first week after tagging and the remainder during the following 3 weeks. Some (22) of these fish were retaken by weirs northeastward towards the head of the bay. The remainder (28) were retaken by purse seiners in the deeper waters of the bay.

Two Island Harbour Tagging

On September 24, 1,460 herring were tagged and released from the Good Luck weir, Two Island Harbour, Grand Manan. Three recaptures were made, 1 in the first week after tagging, another in the second week (both within 2 miles of the tagging site) and the third during the sixth week at Pats Cove about 3 miles away.

Lobster Cove Tagging

On October 15, 2,169 herring were tagged and released from Bradley's stop seine in Lobster Cove, Boothbay Harbor, Maine. The 2 recaptures were made in Linekin Bay, Boothbay Harbor, 5 days later.

Capitol Island Tagging

On October 17, 2,935 herring were tagged and released from Swett's stop seine at Capitol Island, Boothbay Harbor, Maine. The single recapture was made 3 days later in Linekin Bay, Boothbay Harbor.

Additional Taggings

No recaptures were recorded from 1,126 herring tagged at Sandy Cove, Digby Neck, N.S., on June 25; from 1,480 herring tagged at Chandler Bay, Maine, on July 8; from 2,128 herring tagged at Cedar and Laireys Island, Maine, on August 19; and from 1,460 herring tagged at Long Pond Bay on September 23.

DRIFT BOTTLE AND TAG RECOVERIES

During 35 of the tagging experiments in 1958, a total of 1,725 drift bottles were released at the same time as the tagged fish to discover whether there was a relationship between herring movements and the drift of surface waters. Usually 48 drift bottles were released during each tagging. Bottle recoveries varied from 4.2 to 89.7% with an overall average of 31.5% (Table III).

In some cases, the tagged herring and the drift bottles moved in the same direction; in other cases, they moved in the opposite direction. In many instances, there was no apparent relationship between the direction of the tagged fish and bottle movements.

TABLE III. Drift bottle releases and recoveries, 1958.

Location	Date	Releases	Recoveries	
			no.	%
Red Head Harbour, N.B.	Mar. 11	48	14	29.2
East Wolf Island, N.B.	Mar. 18	48	17	35.4
Seely Cove, N.B.	Mar. 20	48	6	12.5
Maces Bay, N.B.	Apr. 9	48	8	16.7
Crow Cove, N.B.	Apr. 10	48	5	10.4
Fox Island, N.B.	May 2	48	18	37.6
Loring Cove, Me.	May 9	48	19	39.6
Hope Island, Me.	May 16	48	16	33.3
Birch Cove, N.B.	May 16	48	43	89.7
Mascarene Shore, N.B.	May 22	48	14	29.2
St. Andrews Point, N.B.	May 29	48	13	27.0
New River Island, N.B.	June 4	48	16	33.3
Bean Island, N.B.	June 10	48	11	22.9
Mill Cove, N.B.	June 17	48	9	18.7
Moose River Cove, Me.	June 17	48	5	10.4
Bean Island, N.B.	June 19	48	17	37.5
Griffin Cove, N.S.	June 24	48	15	31.3
Sandy Cove, N.S.	June 25	48	2	4.2
Spider Cove, N.B.	July 2	48	14	29.2
St. Andrews Point, N.B.	July 3	48	24	50.0
Bocabec Bay, N.B.	July 4	48	38	79.2
Chandler Bay, Me.	July 8	48	6	12.5
East Bay, Me.	July 10	48	23	48.0
Navy Island, N.B.	July 25	48	15	31.3
Dipper Harbour, N.B.	July 31	44	6	13.4
New River Beach, N.B.	Aug. 1	48	8	16.7
Eagle Island, N.B.	Aug. 6	48	22	45.9
Cedar and Laireys, Is., Me.	Aug. 19	48	7	14.6
Sprucehead Island, Me.	Aug. 20	48	34	70.8
Seely Cove, N.B.	Aug. 20	48	8	16.7
Gleason Cove, Me.	Aug. 26	48	15	31.3
McCann Cove, N.B.	Aug. 29	48	34	69.5
Holt Point, N.B.	Sept. 4	48	8	16.7
Passamaquoddy Bay, N.B.	Sept. 5–6	49	20	40.8
Long Pond Bay, N.B.	Sept. 23	48	4	8.3
Two Island Harbour, N.B.	Sept. 24	48	9	18.7
Total		1,725	543	31.5

DISCUSSION AND CONCLUSIONS

The purpose of the tagging experiments was to determine the pattern of movement of herring in the Passamaquoddy area and hence to provide information that would assist in predicting the effects that the proposed tidal power project (Hart and McKernan, 1960) might have on the herring fisheries in the area. Taggings were done during the commercial fishing season and it is believed that the movements of tagged fish are indicative of the movements of herring supporting the fishery.

No comparisons of the amount of movement in different directions was possible because exact information on the amount of fishing effort was not available. However, the number of weirs fished in an area varies little within a season and the variation in the number of tags recovered in a particular locality may well indicate differences in the amount of movement there.

Distance, duration and direction of movements of herring tagged in 1958 are discussed below and comparisons are made with the results of the 1957 taggings. Recoveries of tagged fish in 1958 varied from 0 to 24.0% (Table I) as contrasted with 0 to 12.7% in 1957 (McKenzie and Skud, 1958). Only scarlet tags were used in 1957 whereas in 1958 scarlet, maroon and yellow tags were used. However differences for the various colours were not related to the extent or direction of movement nor the length of time between tagging and recapture. The only detectable difference was that the percentage recovery was considerably higher for scarlet tags (4.5%) than for maroon (2.2%) or yellow (0.2%) tags.

Distances Moved

Analyses of movements of fish are based chiefly on recaptures made more than 2 miles from the points of release. These include 1,179 recaptures or nearly 44% (approximately 47% in 1957) of the total recaptures from 1958 taggings.

Table IV shows that more than 6% of the recaptures in 1958 were made within 2 to 5 miles and over 25% within 5 to 10 miles of the points of release. At greater distances, recaptures declined sharply. The greatest distance moved was 55 miles. Except for minor variations in percentage recoveries results were the same for 1957 (Table V). Some herring travelled long distances within short periods. The average minimum rate of movement for tagged herring that moved from 20 to 55 miles was 1.0 mile per day with a range of 0.2 to 11.3 miles per day. Recovery data did not show the amount of wandering between points of release and recapture. However it is interesting, and perhaps significant, that the maximum rate of movement (11.3 miles per day) is very similar to calculated speeds (10 miles per day) for non-tidal surface currents in the area (Trites, 1959).

TABLE IV. Recaptures of tagged herring at various distances from points of release (1958).

Taggings	0–2	2–5	Distance in miles 5–10	10–25	25–55	Total
Long Island Bay, N.B.	4	0	0	3	...	7
Red Head Harbour, N.B.	44	0	10	...	...	54
East Wolf Island, N.B.	90	0	36	17	...	143
Seely Cove, N.B.	1	7	2	...	...	10
Maces Bay, N.B.	3	0	0	1	...	4
Crow Cove, N.B.	0	0	0	1	...	1
Fox Island, N.B.	1	3	8	31	...	43
Loring Cove, Me.	0	1	227	6	...	234
Birch Cove, N.B.	631	51	11	15	...	708
Hope Island, Me.	41	...	...	...	...	41
Mascarene Shore, N.B.	0	2	88	1	...	91
St. Andrews Point, N.B.	4	20	117	3	...	144
New River Island, N.B.	11	0	0	3	...	14
Bean Island, N.B.	2	7	15	43	...	67
Mill Cove, N.B.	163	2	8	4	3	180
Moose River Cove, Me.	1	1	16	6	6	30
Bean Island, N.B.	17	11	31	52	1	112
Griffin Cove, N.S.	2	0	0	0	1	3
Spider Cove, N.B.	270	1	23	41	...	335
St. Andrews Point, N.B.	2	5	23	1	...	31
Bocabec Bay, N.B.	74	12	3	23	...	112
Sprucehead Island, Me.	1	...	...	...	...	1
East Bay, Me.	56	2	2	3	...	63
Great Chebeague Is., Me.	1	...	...	...	...	1
Linekin Bay, Me.	1	...	...	...	...	1
Navy Island, N.B.	0	4	13	0	2	19
Dipper Harbour, N.B.	0	0	3	16	...	19
New River Beach, N.B.	55	0	0	4	...	59
Eagle Island, N.B.	1	0	0	1	...	2
Seely Cove, N.B.	0	1	7	3	...	11
Sprucehead Island, Me.	1	...	...	...	...	1
Gleason Cove, Me.	4	5	3	32	...	44
McCann Cove, N.B.	3	18	3	...	...	24
Holt Point, N.B.	20	3	...	...	...	23
Passamaquoddy Bay, N.B.	0	16	34	...	...	50
Two Island Harbour, N.B.	2	1	...	...	...	3
Lobster Cove, Me.	2	...	...	...	...	2
Capitol Island, Me.	1	...	...	...	...	1
Totals	1,509	173	683	310	13	2,688
Percentage	56.1	6.4	25.4	11.6	.3	100

TABLE V. Recaptures of tagged herring at various distances from points of release (1957).

Taggings	Distance in miles 0–2	2–5	5–10	10–25	25–55	Total
Moat Island, N.B.	1	3	7	0	2	13
Harbour de Loutre, N.B.	12	0	3	8	0	23
Bocabec, N.B.	101	7	2	12	6	128
New River Beach, N.B.	20	10	7	11	0	48
Pats Cove, N.B.	7	0	8	4	14	33
Lords Cove, N.B.	13	0	24	2	...	39
Frost Cove, Me.	0	18	4	9	1	32
McDougal's Island, N.B.	29	13	13	6	...	61
Bucks Harbor, Me.	1	0	0	0	1	2
Johnson Bay, Me.	47	0	6	6	1	60
Bocabec, N.B.	3	0	...	...	...	3
Cumberland Shore, N.B.	0	0	0	0	2	2
Totals	234	51	74	58	27	444
Percentage	52.7	11.5	16.6	13.1	6.1	100

Time at Large

There was considerable variation in the length of time between tagging and recapture. In 1958, 24.4% of the recaptures were made during the first week, 36.5% during the second week, and 18.8% during the third week (Table VI). The remainder (20.3%) were spread over a period of 4 to 24 weeks after tagging. The average time between release and recapture was 17 days but the variation was from a few hours to 165 days. In both 1957 and 1958 more than 90% of the recaptures were made within the first 5 weeks. However, in 1957 all recaptures were made within 12 weeks (Table VII), the maximum time at large being 82 days.

In general, for both 1957 and 1958, the numbers of tagged fish retaken near the tagging site (0 to 2 miles) declined with time while those retaken farther away (2 to 55 miles) increased (Table VIII).

Table IX gives the time lapse between release and recapture for long distance (20 to 55 miles) travellers for 1957 and 1958 taggings combined. There is no apparent order in the average number of days taken to travel various distances and the conclusion must be that a great deal of wandering takes place.

Direction of Movement

Almost half of the recaptures from the 1957 and 1958 taggings were made more than 2 miles away from the tagging sites (Table VIII). The pattern of distant recaptures indicated that herring movements were usually in more than one direction with no regular seasonal differences in direction.

TABLE VI. Recaptures of tagged herring at weekly intervals following tagging (1958).

Taggings	Time to recapture									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9–24th	Total
Long Island Bay, N.B.	4	0	3	...	...	...	...	...	...	7
Red Head Harbour, N.B.	11	5	13	5	9	2	1	0	8	54
East Wolf Island, N.B.	16	5	9	53	35	9	3	5	8	143
Seely Cove, N.B.	3	0	3	0	3	1	...	...	...	10
Maces Bay, N.B.	2	1	0	0	0	1	...	...	...	4
Crow Cove, N.B.	0	0	0	0	0	0	0	0	1	1
Fox Island, N.B.	11	0	11	8	4	2	0	0	7	43
Loring Cove, Me.	5	64	136	13	9	0	2	1	4	234
Birch Cove, N.B.	170	399	35	31	5	19	5	6	38	708
Hope Island, Me.	9	32	...	...	...	...	...	...	...	41
Mascarene Shore, N.B.	46	18	9	1	0	6	2	1	8	91
St. Andrews Point, N.B.	56	51	3	2	12	6	5	0	9	144
New River Island, N.B.	2	0	3	3	0	3	2	1	...	14
Bean Island, N.B.	0	2	32	10	8	4	3	3	5	67
Mill Cove, N.B.	54	2	103	10	9	1	0	0	1	180
Moose River Cove, Me.	0	3	2	2	4	17	1	0	1	30
Bean Island, N.B.	23	48	9	14	8	3	4	0	3	112
Griffin Cove, N.S.	2	1	...	...	...	...	...	...	...	3
Spider Cove, N.B.	71	171	77	8	6	0	1	0	1	335
St. Andrews Point, N.B.	7	12	6	2	0	1	1	1	1	31
Bocabec Bay, N.B.	24	63	7	8	0	0	0	6	4	112
Sprucehead Island, Me.	0	1	...	...	...	...	...	...	...	1
East Bay, Me.	11	29	20	1	0	1	0	0	1	63
Great Chebeague Is., Me.	1	...	...	...	...	...	...	...	...	1
Linekin Bay, Me.	1	...	...	...	...	...	...	...	...	1
Navy Island, N.B.	0	0	0	3	2	1	7	1	5	19
Dipper Harbour, N.B.	15	1	1	0	2	...	...	...	...	19
New River Beach, N.B.	53	1	1	0	0	3	0	0	1	59
Eagle Island, N.B.	1	0	0	0	0	1	...	...	...	2
Seely Cove, N.B.	6	2	2	1	...	...	...	...	...	11
Sprucehead Island, Me.	1	...	...	...	...	...	...	...	...	1
Gleason Cove, Me.	7	21	14	1	1	...	...	...	...	44
McCann Cove, N.B.	4	16	3	0	0	1	...	...	...	24
Holt Point, N.B.	12	11	...	...	...	...	...	...	...	23
Passamaquoddy Bay, N.B.	23	22	2	3	...	...	...	...	...	50
Two Island Harbour, N.B.	1	1	0	0	0	1	...	...	...	3
Lobster Cove, N.B.	2	...	...	...	...	...	...	...	...	2
Capitol Island, Me.	1	...	...	...	...	...	...	...	...	1
Totals	655	982	504	179	117	83	37	25	103	2,688
Percentage	24.4	36.5	18.8	6.7	4.4	3.1	1.4	.9	3.8	100

TABLE VII. Recaptures of tagged herring at weekly intervals following tagging (1957).

Taggings	Time to recapture 1st	2nd	3rd	4th	5th	6th	7th	8th	9–12th	Total
Moat Island, N.B.	0	1	5	4	1	0	0	0	2	13
Harbour de Loutre, N.B.	8	6	6	3	...	...	...	...	...	23
Bocabec, N.B.	72	40	12	0	2	1	1	...	...	128
New River Beach, N.B.	26	12	4	4	0	0	0	0	2	48
Pats Cove, N.B.	14	10	2	3	2	0	0	0	2	33
Lords Cove, N.B.	14	15	1	4	0	1	3	1	...	39
Frost Cove, Me.	11	15	4	1	0	1	...	...	...	32
McDougal's Island, N.B.	34	14	3	10	...	...	...	...	...	61
Buck's Harbor, Me.	0	1	1	...	...	...	...	...	...	2
Johnson Bay, Me.	48	2	5	5	...	...	...	...	...	60
Bocabec, N.B.	3	...	...	...	...	...	...	...	...	3
Cumberland Shore, N.B.	2	...	...	...	...	...	...	...	...	2
Totals	232	116	43	34	5	3	4	1	6	444
Percentage	52.2	26.1	9.7	7.7	1.1	0.7	9.9	0.2	1.4	100

TABLE VIII. Percentage recaptures of herring within and outside tagging areas by weekly periods 1957 and 1958.

Weekly periods	1957 within (0–2 miles)	1957 outside (2–55 miles)	1958 within (0–2 miles)	1958 outside (2–55 miles)
	%	%	%	%
1st	69	31	65	35
2nd	47	53	67	33
3rd	19	81	41	59
4th	35	65	60	40
5th	0	100	45	55
6th	0	100	28	72
7th	0	100	19	81
8th	0	100	40	60
9th–24th	0	100	15	85
Average	53	47	56	44

TABLE IX. Time lapse between release and recapture of tagged herring that moved 20 to 55 miles (1957 and 1958 taggings).

Distance (miles)	No. of fish	Days from release to recapture Min.	Max.	Av.
20–25	48	2	101	32
25–30	15	6	60	20
30–35	11	7	69	22
35–40	8	4	63	26
40–45	3	16	34	26
45–55	3	9	102	43

EAST OF PASSAMAQUODDY BAY. Herring tagged east of Passamaquoddy Bay in both 1957 and 1958 were recaptured chiefly near the tagging site following the general recovery pattern. However, taggings in March and April 1958 showed that there was some movement westward to Passamaquoddy Bay. No tagging was done east of the bay in May. From the one June tagging (1958) there were recaptures both westward to Passamaquoddy Bay and eastward to Saint John. July and August taggings showed a complex recapture pattern. In July 1957 recaptures from a tagging at New River Beach indicated a pronounced movement westward to Passamaquoddy Bay. A tagging in July 1958 showed an equally well pronounced movement eastward towards Point Lepreau although a few recaptures were made in the bay itself. Another tagging in July 1958 showed eastward movement only as no recaptures were made either locally or westward (Fig. 9). From a tagging at New River Beach on August 1, 1958, there were only 4 distant recaptures, all westward in Passamaquoddy Bay (Fig. 9). From a tagging 3 weeks later (August 20, 1958) at Seely Cove, about 5 miles from New River Beach, recoveries were made from both directions; eastward nearly to Saint John and westward to Passamaquoddy Bay. There were no taggings east of the bay in September. The only autumn tagging east of this bay (Cumberland Shore, October 2, 1957) gave 2 recaptures both about 25 miles eastward towards Saint John.

Altogether there were 12 taggings done east of Passamaquoddy Bay from March to October, 2 in 1957 and 10 in 1958. The recoveries as a whole indicated that during most of the year herring moved randomly in two directions along the shore; westward as far as the bay and eastward as far as Saint John.

SOUTH OF PASSAMAQUODDY BAY. Taggings south of Passamaquoddy Bay were carried out at The Wolves Islands, at Grand Manan, and on the Nova Scotia side of the Bay of Fundy. The tagging at The Wolves (East Wolf Island) was done on March 18, 1958 (Fig. 3). There were 5 taggings at Grand Manan, 1 in August and 1 in November, 1957, 1 in March and 2 in September, 1958. The pattern of recapture from the tagging at The Wolves indicated that a body of herring lay offshore there during most of April and early May but moved inshore at irregular intervals where they were caught with shut-off seines. All of the local recaptures (90) were made from catches on April 7, 19, 24 and May 8, and these were the only 4 commercial catches made at The Wolves during this period.

Distant recaptures (53) from The Wolves tagging were made chiefly northeastward along the shore from Beaver Harbour to Maces Bay although 5 were recaptured in Passamaquoddy Bay. In contrast to the recovery pattern at the tagging site, the distant recaptures were spread out over a period of 4 months (March 24 to July 18), at least 25 separate catches were involved and with one possible exception, not more than 3 tags were recovered from any single catch.

From two of the taggings at Grand Manan (White Head, November 1957

and Long Pond Bay, September 1958) there were no recoveries. From a tagging at Two Island Harbour (September 1958) there were 3 recaptures, all at the tagging site. From a tagging at Long Island Bay (March 1958) there were 7 recaptures, 4 in the tagging area and 3 northeastward in Maces Bay.

The most informative Grand Manan tagging was done at Pats Cove in August 1957 (Fig. 10). Recaptures showed two distinct movements; one westward to the coast of Maine and the other northward to Passamaquoddy Bay. The recaptures on the coast of Maine were made at Jonesport and Cape Split from 35 to 40 miles from the tagging site. Of the 15 recaptures in the bay area, 8 were made near the eastern entrance (Letite Passage) to the bay and the other 7 at the head of the bay.

Although conclusions are based chiefly on only 2 taggings (East Wolf Island and Pats Cove) there is a suggestion of a rather pronounced movement of herring from the offshore areas of The Wolves and Grand Manan towards Passamaquoddy Bay and the area between the bay and Point Lepreau. The recaptures at Jonesport and Cape Split suggest a slight movement from Grand Manan westward to the coast of Maine.

From taggings on the Nova Scotia side of the Bay of Fundy only 1 (from Griffin Cove tagging, June 24, 1958) of the 8,467 herring tagged is known to have crossed to the Passamaquoddy area. Only 2 are known to have crossed in the opposite direction, 1 from the Mill Cove, Campobello tagging on June 17, 1958, and 1 from the Navy Island tagging on July 25, 1958.

WEST OF PASSAMAQUODDY BAY. There were 13 taggings westward of Passamaquoddy Bay, 3 in 1957 and 10 in 1958. From all but 2 taggings, recoveries were mainly local providing little information on herring movements. From a tagging (September 1957) at Buck's Harbor, Maine, about 25 miles westward of the bay, there were only 2 recaptures, 1 local and the other about 50 miles to the eastward near Point Lepreau (McKenzie and Skud, 1958). There were 30 recoveries from a tagging (June 1958) at Moose River Cove, Maine, about 10 miles west of Passamaquoddy Bay (Fig. 8). Two recaptures were made near the tagging site, 17 westward (10 to 15 miles) along the coast of Maine, 1 southeastward (12 to 15 miles) to Grand Manan, 8 northeastward (20 to 40 miles) along the shore between Letite Passage and Dipper Harbour, and 2 inside Passamaquoddy Bay. The results indicate some movement of herring from the east part of the coast of Maine to the Passamaquoddy area and farther east but none from the more westerly Maine shore. This suggests differences in the herring from eastern and western Maine waters and is in agreement with the conclusions reached by Sindermann (1957a and b) and Sindermann and Mairs (1959) that there is a difference in the herring stocks east and west of Mount Desert Island.

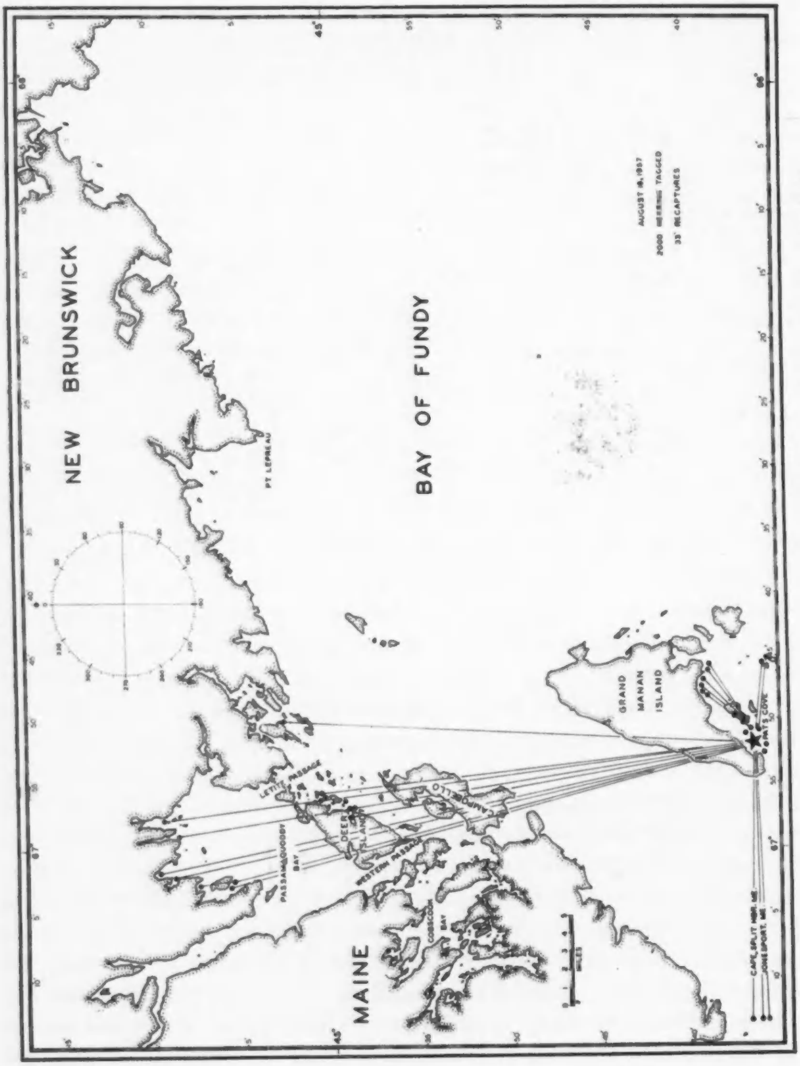

FIG. 10. Recaptures from herring tagged at Pats Cove, N.B., on August 16, 1957.

ENTRANCES TO PASSAMAQUODDY BAY. Tagging among the islands at the mouth of Passamaquoddy Bay in both 1957 and 1958 showed that in May almost half of the tagged herring moved rapidly into the bay while the other half moved eastward towards Point Lepreau (Fig. 4). From June taggings 56.5% of the recaptures were made near the tagging sites, 38.2% inside the bay, and 5.3% to the eastward (Fig. 11). From July taggings 83.6% of the recaptures were made near the tagging site, 14.6% to the eastward, and 1.8% inside Passamaquoddy Bay. Most (95%) of the recaptures from August taggings were made among the islands or within the bay, none eastward. There was no tagging done in September in this area. Almost all (99%) of the recaptures from October taggings were made either near the tagging sites (93%) or inside Passamaquoddy (6%).

Recaptures in the passages were few, possibly because there are not many weirs in these areas. However, the few recoveries indicated that most entries and exits were via Letite Passage rather than Western Passage.

INSIDE PASSAMAQUODDY BAY. Most recoveries from taggings inside Passamaquoddy Bay were made within the bay, some were made among the islands at the mouth of the bay and some about 27 miles eastward along the shore as far as Musquash. There is only 1 record (questionable) of a recapture made to the westward along the coast of Maine.

Taggings in the outer half of Passamaquoddy Bay demonstrated a movement to the head of the bay (e.g., Loring Cove, May 9, 1958, Fig. 5, and Mascarene Shore, May 22, 1958, Fig. 7) while taggings at the head of the Bay showed most of the recaptures at the tagging site, (e.g., Birch Cove, May 16, 1958, Fig. 6). However, the taggings in both parts of Passamaquoddy Bay yielded about the same proportion of recaptures outside the bay. The earliest taggings in the bay were carried out in May (11,379 herring tagged) and of the 1,177 recaptures, 96.9% were retaken inside and 3.1% among the islands at the mouth and farther away—usually eastward. No taggings were carried out in Passamaquoddy Bay in June. In July of the two years 11,830 herring were tagged and 290 were recaptured—17.6% from among the islands at the mouth of the bay or eastward. All the recaptures from August taggings (5,574 fish tagged) in Passamaquoddy Bay were made inside the bay. In September, 166 of the 10,461 tagged fish were recaptured and of these, 7.2% were recaught outside the bay. The October taggings of 2,963 herring yielded only 3 recaptures, all within Passamaquoddy Bay. These taggings thus showed that many fish moved out of the bay during the season and that in July, especially in 1958, this movement reached its peak.

COBSCOOK BAY. On the whole taggings showed much less movement in and out of Cobscook Bay than Passamaquoddy Bay. Of the 57 taggings carried out in 1957 and 1958 outside of Cobscook Bay only 2 yielded any recaptures within this bay—1 from the Frost Cove tagging in 1957 and 1 from the Mill Cove tagging in 1958. Although the average annual catch of herring (1947 to 1958) in Passamaquoddy Bay (McKenzie and Tibbo, 1960) is nearly 6 times greater than in Cobscook Bay (Scattergood and Lozier, 1959), tag recoveries in Passamaquoddy Bay from releases outside were more than 100 times those in Cobscook Bay.

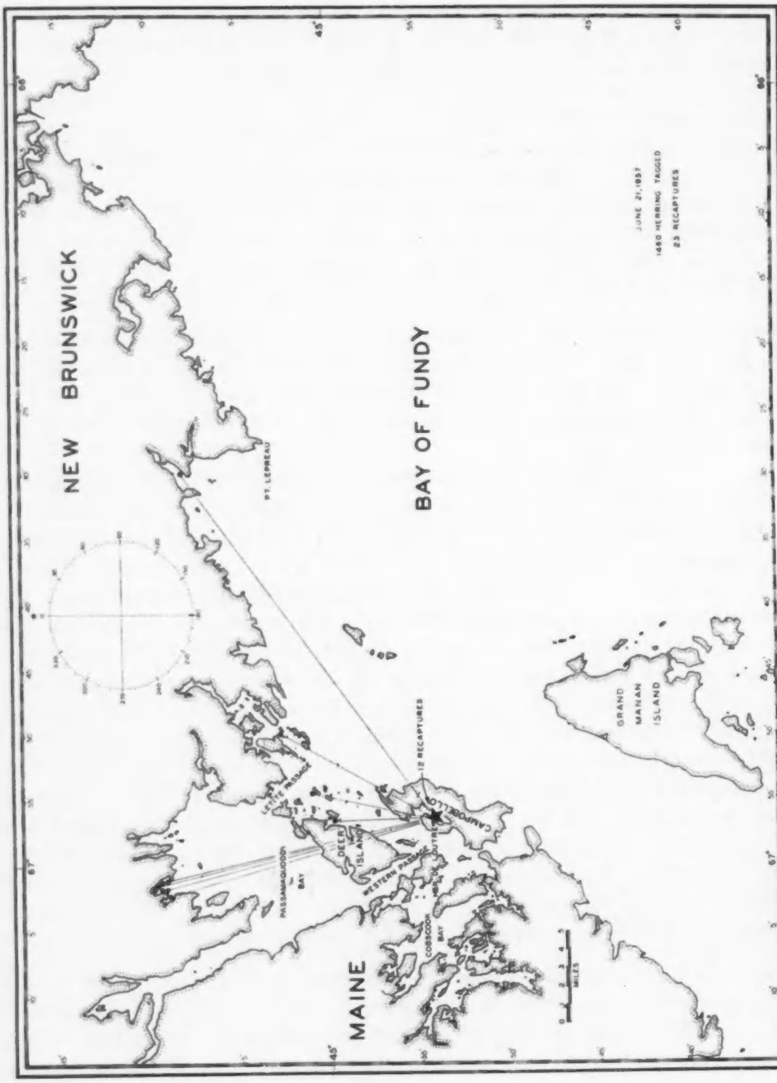

FIG. 11. Recaptures from herring tagged at Harbour de Loutre, N.B., on June 21, 1957.

RECAPITULATION. The overall results of the tagging experiments in 1957 and 1958 showed that, during the spring and early summer (March to June), the movement of herring was, in general, into Passamaquoddy Bay and along the shore eastward almost to Saint John. In July the inward movement continued but there appeared to be a greater movement outwards and to the eastward. The inward movement continued in August but the outward movement declined. Tagging in September and October showed much less movement in all directions than at other times of year.

The variations in recaptures in the different regions occurred in spite of the fact that there is little change in the number of weirs fishing until late in October or early November. The Charlotte County herring fishery is at its peak in August outside of Passamaquoddy Bay and in September inside the bay (McKenzie and Tibbo, 1960). With 80 to 90% of the tags being recovered within a month of release there was adequate time for tags to be recovered (from taggings prior to mid-September) before any of the weirs ceased fishing.

The heavy fishery carried on during most of the summer and autumn in 1957 at the head of Passamaquoddy Bay reflected the concentration of herring there as indicated by the tagging. The movement towards Point Lepreau and Saint John County in July–August 1958 was confirmed by a substantial increase in the fishery in that area.

There is insufficient evidence from drift bottle experiments to establish any definite relationship between surface drift and herring movements. Tagged herring appeared at times to move neither with nor against the current. The surface layer may, however, be very shallow at such times and hence have no effect on the movements of fish. Generally, there was a greater tendency to swim against the current than in any other direction.

These tagging experiments have shown that herring moved freely in and out of Passamaquoddy and Cobscook Bays during the fishing season from May to October with some tendency to concentrate at the head of Passamaquoddy Bay. It is expected that the installation and operation of the proposed Passamaquoddy power dams would not affect the movement of herring to the Passamaquoddy area nor should it affect the distribution of fish except in Passamaquoddy and Cobscook Bays and immediately outside the dams. Herring should arrive outside the dams and filling gates in both Western and Letite Passages as before, but with filling gates open for only 5 to 6 hours each day (Trites, MS, 1959), the movement of fish into Passamaquoddy Bay will be delayed. This would affect the rate at which herring accumulate inside the bay. However, percentage recapture of tagged fish and the results of sonic sounder cruises in the Passamaquoddy area (Tibbo and Brawn, 1960) suggest that fishing mortality is low and there should be no reduction in the overall abundance of herring inside the bay. If the project is constructed, herring will not be able to enter Cobscook Bay directly from the outside. Entry into Cobscook Bay and exit from Passamaquoddy Bay will then be possible only through the turbines which lead into Cobscook Bay. As a result, movement into Cobscook Bay and away from both bays would be altered both in time and direction.

ACKNOWLEDGMENTS

The authors are pleased to acknowledge the co-operation of herring fishermen, plant operators and employees in returning tags. Grateful appreciation is extended to K. E. Bates, J. P. Cowie, F. W. Durant, and W. C. Hodges for the purchase and careful recording of tags. Records of returns in the United States were handled by H. C. Boyar, C. Larsen, and J. P. Wentworth.

Special acknowledgment is made of the co-operation of Mr L. W. Scattergood, U.S. Bureau of Commercial Fisheries, Boothbay Harbor laboratory, for permission to use the results of 10 tagging experiments carried out under his direction and for providing technical assistance in many of the other taggings.

The authors appreciate the extra time and effort given and the enthusiasm with which the technical personnel of the Pelagic Fish Investigation of the Fisheries Research Board of Canada at St. Andrews, N.B., carried out the field program.

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Oceanographic Activities of the Polar Continental Shelf Project[1]

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One of the primary research objectives of the Canada Department of Mines and Technical Surveys' Polar Continental Shelf Project has been a detailed investigation of the characteristics and movement of the waters overlying the polar continental shelf and passing through the channels of the Canadian Arctic Archipelago. The program included sub-surface observations of temperature, salinity, and dissolved oxygen. Bottom samples and plankton collections were made at all stations, and at selected locations micro-thermal measurements were taken within the shallow, seasonal layer which forms directly under the ice.

Since the Project was initiated in 1958, two field seasons have been completed at Isachsen, N.W.T., with encouraging results. During the summer of 1959 emphasis was placed on the development of equipment and techniques by which precise oceanographic observations could be taken on the ice using a light, single-engined aircraft as the means of transportation.

Climatic conditions in the Isachsen area offer rather severe restrictions to normal flying procedures. The time during which fixed-wing aircraft may operate on the sea ice with the greatest efficiency is restricted to April and May. During this period the average air temperature is –15°F; however, in 1959 oceanographic observations were undertaken at temperatures as low as –46°F. Under these conditions recording of sub-surface temperatures and the collection of water samples for salinity and dissolved oxygen determination require very careful handling and precise operating techniques.

Procedures and Equipment

To ensure uniformity in the operation of the deep-sea thermometers and to prevent the samples from freezing, the 1960 observations were carried out in a heated tent placed over the hole in the ice through which the instruments were lowered. Using four double-burner camp stoves it was possible to keep the temperature in the tent above freezing during the time the recordings were being taken. Water samples for salinity and dissolved oxygen analysis were stored in a warmed, insulated box and were sent back to the main base at Isachsen with the first available aircraft. These precautions proved successful in that only six water samples were lost through freezing during the 1960 field season.

Throughout the survey area the thickness of the sea ice varies from a maximum of over 8 m to a minimum of only a few centimetres. The average ice thickness measured in the frozen leads at each of the oceanographic stations was 190 cm. Areas where aircraft landings are possible are restricted to leads which

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have frozen during calm conditions, thus producing a smooth, hard surface which is ideal as a landing strip for light aircraft. Fortunately, frozen leads of this type were common in the sea ice in the vicinity of Isachsen and little difficulty was experienced in landing close to the position determined for the oceanographic stations. In a few instances where ice conditions made it impossible to land a fixed-wing aircraft, the oceanographic camp was transported to the position by an S-55 helicopter. The time required at each site varied from 4 to 10 hours; however, at most stations the camp remained on the site for several days while the aircraft were busy with other commitments, or when weather conditions made flying impossible. The exact location of each station was determined by reference to a fixed beacon in the survey traverse or from Decca co-ordinates.

The oceanographic equipment which had been prepared for the Project consisted primarily of unmodified sea-going apparatus. Knudsen reversing water bottles fitted with double thermometer racks, and glass Copenhagen-type salinity sample bottles were used at all stations.

The ice drill which produced the best results was powered by a McCulloch Model 99 chain-saw engine fitted with a drilling turntable. In place of the normal earth auger attachment for this drill, a 12-foot adjustable section of diamond drill "A" rod fitted with a plate-type ice auger 10 inches in diameter was susbstituted. This equipment produced a clean, 10-inch-diameter hole through 6 feet of ice in approximately 15 minutes.

The winch used in 1959 was a small aircraft-target towing unit powered by a 1½-hp McCulloch engine, and proved quite satisfactory. However, in 1960 larger capacity winches were designed specifically to meet the weight and capacity specifications which were required. The 1960 oceanographic winch was built almost entirely of aluminum and was powered by a 2½-hp, 4-cycle Briggs and Stratton engine connected through a two-speed chain drive to a drum of 1500 m capacity. With minor modifications the machine proved quite satisfactory and reliable under all weather conditions that were encountered.

Four oceanographic stations were occupied in the Prince Gustaf Adolf Sea in May 1959. At the same time tests were carried out with Ott and Ekman current meters in an effort to determine if this type of meter was suitable for use in the area.

Between April 19 and June 3, 1960, a programme of 17 oceanographic stations was completed across the passages between Axel Heiberg Island and Prince Patrick Island and in a traverse extending 228 km to the northwest across the continental shelf (Fig. 1). In conjunction with the oceanographic observations taken at each site, supplementary records of soundings, ice conditions and local weather were kept at each location.

Oceanographic procedures at all stations included observation of sub-surface temperatures, collection of samples for salinity and dissolved oxygen determination and plankton analyses, making vertical net hauls for zooplankton collections, and taking cores of the bottom sediments. Bathythermograph observations were made at all stations, and at one location a series of wire-angle observations was taken using a Japanese-type wire-angle gauge.

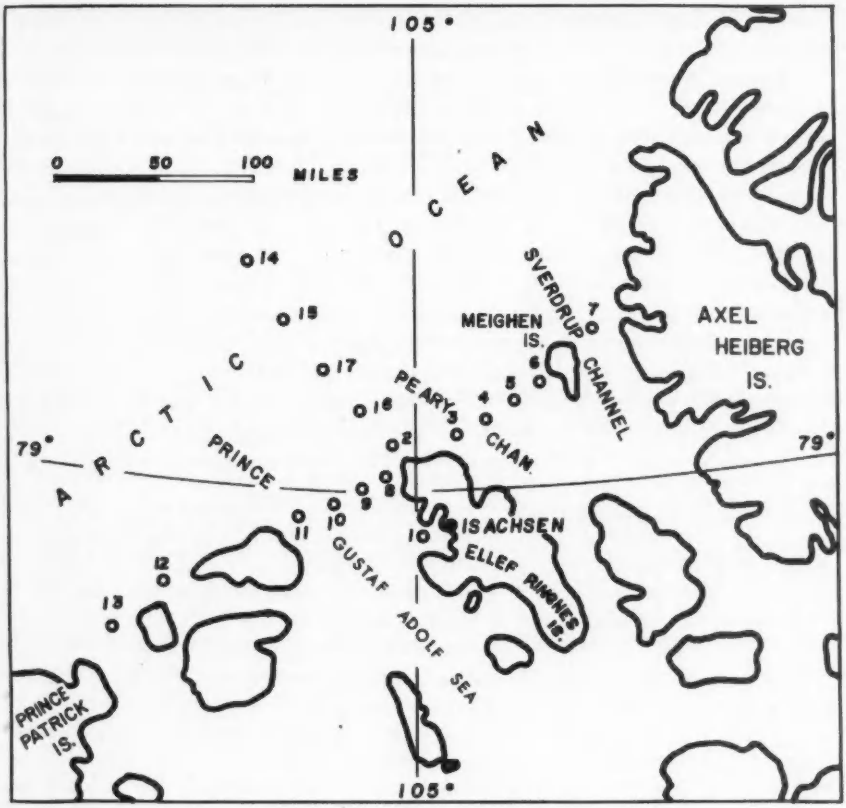

FIG. 1. Location of Polar Continental Shelf Project (1960) oceanographic stations.

Results

Knowledge of the bathymetry of the continental shelf in the vicinity of Isachsen was virtually non-existent prior to the 1959 survey. The few scattered soundings that were available gave indication of relatively deep channels to the north and south of Ellef Ringnes Island, but little evidence of the extent of the continental shelf. The IGY soundings along the track of Ice Island T-3 defined the position of the seaward margin of the continental shelf at several locations along the western arctic coast (Crary and Goldstein, 1957; Collin, 1959). Information from the U.S.S.R. indicated a steeply dipping continental slope and indentations in the continental shelf along the off-shore extensions of Sverdrup Channel and the Prince Gustaf Adolf Sea. Soundings taken within the last two years give a much clearer picture of the bathymetry in this region.

In the Cape Isachsen area the continental shelf extends out from shore a distance of 170 km, with water depths of about 500 m at the seaward edge.

Present soundings indicate that the shelf profile at Cape Isachsen is composed of three zones. The inshore section extends to a distance of 9 km at a gentle slope of less than ½°. Beyond this point the coastal slope merges with an extensive, plateau-like area with an almost uniform depth of 500 m. This platform ends abruptly at the edge of the continental slope, at which position the depth increases from 500 m to over 2000 m at a slope of slightly greater than 1½°. The greatest depth recorded on the continental slope during the 1960 field season was 1239 m.

Within the passages to the north and south of Ellef Ringnes Island, channels having a depth of 400 to 500 m were found parallel to the main axis, predominantly along the northern sides of the straits. It does not appear that the deep trough in Peary Channel extends through the continental shelf into the Arctic Basin, although in the Prince Gustaf Adolf Sea there is evidence that the less well-defined channel along the Ellef Ringnes coast is continuous through the continental shelf.

Temperature and salinity graphs (Fig. 2) have been produced from the five

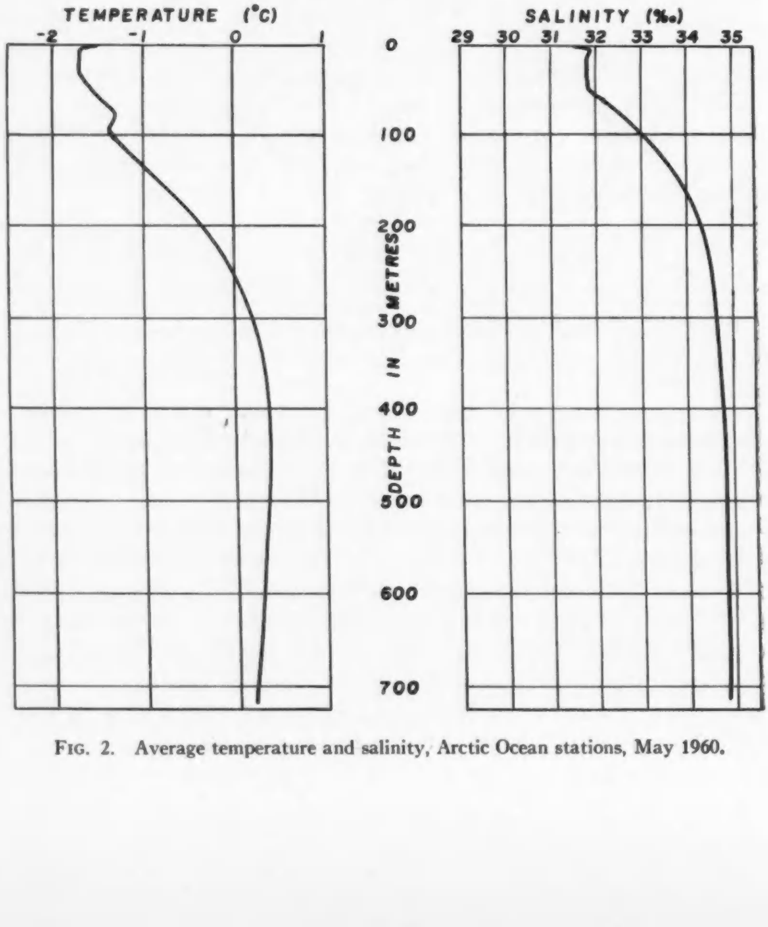

FIG. 2. Average temperature and salinity, Arctic Ocean stations, May 1960.

oceanographic stations (Table I) which were occupied across the continental shelf in the vicinity of Ellef Ringnes Island.

TABLE I. Positions of Polar Continental Shelf Project (1960) Arctic Ocean Stations.

Date	PCSP Station	Latitude N	Longitude W	Depth
				m
April 2	2	79° 25′	105° 56′	143
May 30	14	80° 42′	112° 50′	1239
May 30	15	80° 12′	109° 45′	499
May 30	16	79° 37′	106° 54′	340
May 31	17	79° 52′	108° 20′	487

The data obtained at these stations show that the characteristics of the water on the continental shelf are generally similar to those encountered in the Arctic Basin.

The temperature curve shows a surface layer having temperatures of less than −1.6°C to a depth of 50 m, a definite negative thermal gradient at 75 to 100 m and temperatures greater than 0.0°C between 250 and 800 m.

The interesting temperature structure at 75 m is mentioned by Worthington (1953a, b) and is shown to be a typical feature of the Beaufort Sea. However, at the 1957 and 1958 Ice Island T-3 stations between latitudes 78°N and 83°N there is little indication of this phenomenon (Farlow, 1958; Collin, 1959). Worthington (1953a) suggests that this gradient appears to be the last remnant of a seasonal thermocline which must have been formed in the ice-free areas of the Beaufort Sea during the summers of 1950 and 1951.

A similar explanation may be called upon to account for the appearance of this type of thermocline at the continental shelf stations. At the 1957 and 1958 T-3 stations the ice island was invariably surrounded with sea ice of 10/10 concentration. In comparison, the region of the Polar Continental Shelf Project Stations 2, 15, 16 and 17 is well known as an area of pronounced ice movement. Wide leads form in this region during late May and persist throughout the summer. Thorsteinsson reported several miles of open water in the area off Cape Thomas Hubbard, Axel Heiberg Island, in June 1957 (Blackadar, 1958) and in the summers of 1959 and 1960 leads up to 2 miles wide were reported in the vicinity of Ellef Ringnes Island. Much larger areas of open water were observed to the north and west of Meighen Island in September 1960. It is estimated that at the time of maximum extent 6% of the sea surface within 40 miles of the northwest coast is exposed as open water. The significance of this relatively small area of ice-free water would appear to be negligible. However, the 1960 oceanographic observations seem to indicate that throughout the year, open water areas have a marked effect on water characteristics within the upper 100 m and there is a considerably larger percentage of open water forms in this region than has been hitherto observed.

On the continental shelf the Atlantic layer, as limited by the zero isotherms, was found to extend from approximately 250 m to the bottom at 500 m. At Station 14, on the continental slope, the Atlantic layer was located between 250 and 850 m. The thickness of this layer and the depth of maximum temperature, 0.43°C at 500 m, correspond remarkably well with the information presented by Timofeev (1957).

The general slope of the isobaric surfaces, downward toward the coast, indicates a weak, southwesterly water movement.

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Correlation of Morphological and Intra-ocular Measurements in the Atlantic Salmon (*Salmo salar*) Yearling[1,2]

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ABSTRACT

In the Atlantic salmon yearling, correlation among various morphological measurements is of a higher order than correlation of various intra-ocular measurements. While the latter correlation is positive, it is not of a high enough order to serve as a useful predictive device. Correlation between intra-ocular measurements from the left and the right eyes is also of a low order.

INTRODUCTION

In an earlier histophysiological investigation (Brett and Ali, 1958) of the Pacific salmon (genus *Oncorhynchus*) retina, the thicknesses of the retinal epithelial pigment and cone layers were expressed as percentages of the retinal thickness in the construction of graphs describing the rates of light and dark-adaptation of the retinal elements. In a later, more comprehensive investigation (Ali, 1959) more than 9,000 eyes were examined belonging to various stages of 4 species of Pacific salmon (sockeye, *O. nerka*; coho, *O. kisutch*; pink, *O. gorbuscha*; chum, *O. keta*). It was then concluded that, although the retina and consequently the various retinal elements composing it are thicker in an older, larger stage (e.g. smolt) than in a younger, smaller stage (e.g. alevin), the thicknesses of the retinal elements in the retinae of fishes of the same age group did not vary in direct proportion to the thicknesses of the retinae but did so at random. In view of this, in the graphs constructed to show the effect of various light conditions on the retinal pigment and cone layers, the thicknesses of these layers were plotted directly. These graphs proved quite satisfactory and served their purpose well. In subsequent investigations (Ali and Hoar, 1959; Ali, 1960a) with the Pacific salmon retinae also the same method was followed. In all these studies, graphs were also constructed wherein the thicknesses of the retinal pigment and cone layers were expressed as percentages of the retinal thickness; and indeed, in a recent study (Ali, 1960b) of the retina of Florida chamelon (*Anolis carolinensis*), graphs constructed using direct thicknesses as well as percentages have been presented for comparison. However, since the latter did not differ significantly from those constructed using direct thicknesses and since the exact relationship between the thickness of the retinal elements and the thickness of the retina was not known, the percentages were not accepted as consistent proportions.

In view of this background and in view of the fact that an extensive survey of the histophysiology of the Atlantic salmon retina has been undertaken, it appears desirable that an investigation wherein the relationships among morphological and intra-ocular measurements are ascertained might prove helpful in the

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interpretation of retinal responses to various experimentally induced light conditions.

Moreover, although the length–weight relationship in the Atlantic salmon is known (Hoar, 1939; Carlander, 1953) no investigation has been undertaken to establish the relationship among other morphological and histological characteristics. It is felt that this study will contribute, at least to a small extent, in this regard also.

MATERIAL AND METHODS

MATERIAL

Yearlings obtained from Margaree Hatchery, Frizzleton, Nova Scotia, in March 1960 and reared in the Fish Research Laboratory of the Memorial University, were used. They were kept in wooden tanks with constantly aerated and refrigerated running water. While in the laboratory they were exposed to 16 hours light (25 ft-c) per day. Temperature of the water ranged from 4°C to 10°C. They were fed ground beef liver twice daily.

METHODS

SAMPLING. Fifty fish were sampled under identical conditions (25 ft-c; 8°C) on May 10, 1960, between 10.30 and 11.00 a.m. These were fixed in standard Bouin's fixative. After death, their eyes were punctured at the sclero-corneal junction in order to allow better fixation of the retina. After 48 hours in the fixative, the fish were transferred to 70% alcohol and their lengths, weights and head diameters measured. The eyes were then enucleated and separated. The diameter of each eye was measured at five planes and the average determined. After this, the cornea and lens were removed.

HISTOLOGICAL. The eyes were dehydrated in ascending strengths of alcohol, cleared in xylene and inbedded in paraffin (Fisher Tissuemat; M.P. 54–56°C). Sections were cut at 8 microns, stained with Harris' haematoxylin and counterstained with eosin (water soluble; 5%). The prepared sections, which were mounted in Canada balsam were dried at 37°C before being examined.

MEASUREMENTS. In all eyes, the thicknesses of the retinae, retinal epithelial pigment and cone layers were measured at 5 locations (3 in the peripheral regions and 2 in the region of the fundus). In each case the average of the 5 measurements was considered as the true thickness. The method followed in measuring the various layers was the same as the one used in a previous investigation (Ali, 1959).

STATISTICAL. The correlation carried out was of the simple two-variable rectilinear type. Examination of scatter diagrams indicated that where a significant degree of correlation was in evidence, a straight line fit was not inappropriate. Data for the 50 fish were left ungrouped and the linear correlation coefficients were calculated (Croxton and Cowden, 1955). Confidence limits of correlation coefficients were calculated using the z-transformation of Fisher (1950).

RESULTS

A coefficient of correlation was calculated for each combination of two of the following variables.

Morphological measurements	
Cube root of the weight	$\sqrt[3]{W}$
Length (to fork of tail)	L
Head diameter	H
Left eye thickness	E
Intra-ocular measurements (left eye)	
Retinal thickness	R
Cone layer thickness	C
Pigment thickness	P

The cube root of the weight was used, rather than the weight itself, in order to reduce the weight variable to a dimension approximately comparable with that of the other variables, which were all linear.

The coefficients of correlation found are shown in Table I. If the value

TABLE I. Coefficients of correlation between various sets of morphological and intra-ocular measurements. See text for explanation of symbols. Graphs (Fig. 2–7) are presented for sets of measurements marked by an asterisk (*).

L	+0.92					
H	+0.88	+0.84				
E	+0.88	+0.87	+0.82			
R	+0.31	+0.20	+0.26*	+0.22		
C	+0.43	+0.27*	+0.19	+0.29	+0.43*	
P	+0.34	+0.30	+0.41*	+0.31	+0.42*	+0.44*
	$\sqrt[3]{W}$	L	H	E	R	C

0.70 is taken as the criterion of a useful degree of correlation for predictive purposes, the coefficients found divide quite clearly into those which show useful correlation and those which do not.

COMPARISONS OF MORPHOLOGICAL CHARACTERS

All four of the external morphological characters measured were highly correlated (top 3 rows in Table I). The correlation of the lengths of the fish with the cube root of their weight yielded the highest coefficient, +0.92. As an alternative indication of this relationship, the coefficient of condition of each fish was calculated using the formula (100 W) $\div$ L^3, with the weights recorded in grams and lengths in centimetres (Hoar, 1939). As shown in the accompanying histogram (Fig. 1), the coefficients of condition ranged from 0.4 to 1.0, all but 4

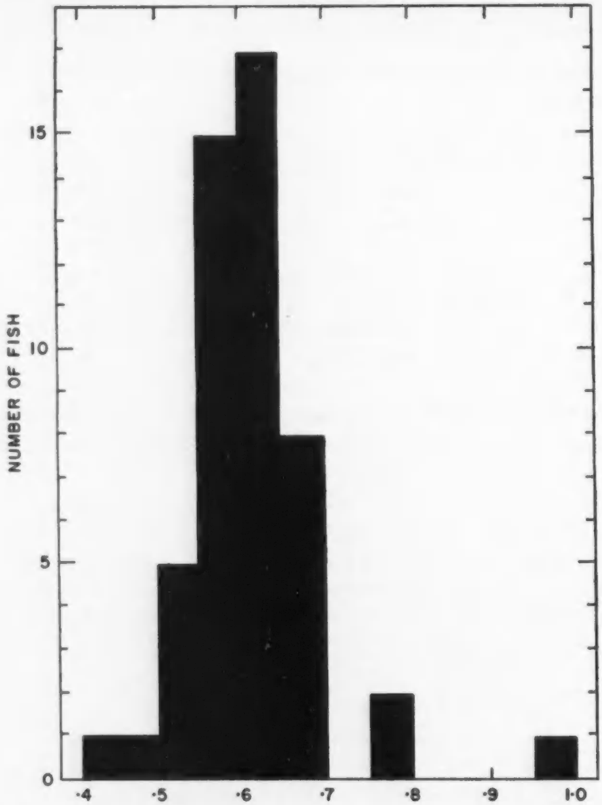

FIG. 1. Histogram showing the frequency distribution of coefficients of condition of the 50 fish used in this investigation.

cases falling in the 0.5 to 0.7 range. This gives an indication of the degree of dispersion in the length-weight relationship which is compatible with the high coefficient of correlation shown.

COMPARISONS OF INTRA-OCULAR CHARACTERS (Fig. 2–4)

Correlations between thickness of retina, cone layer and pigment all yield positive coefficients, but of such low magnitude (0.42–0.44) that they would not be useful for prediction (the 2 right-hand columns of Table I). The highest coefficient in this group, +0.44, has 95% confidence limits of +0.64 and +0.19. At this level of significance, therefore, no coefficient in this group could reach the +0.70 limit of "usefulness". This low level of correlation among the intra-ocular measurements is surprising; it indicates that the characters measured vary independently, for the most part.

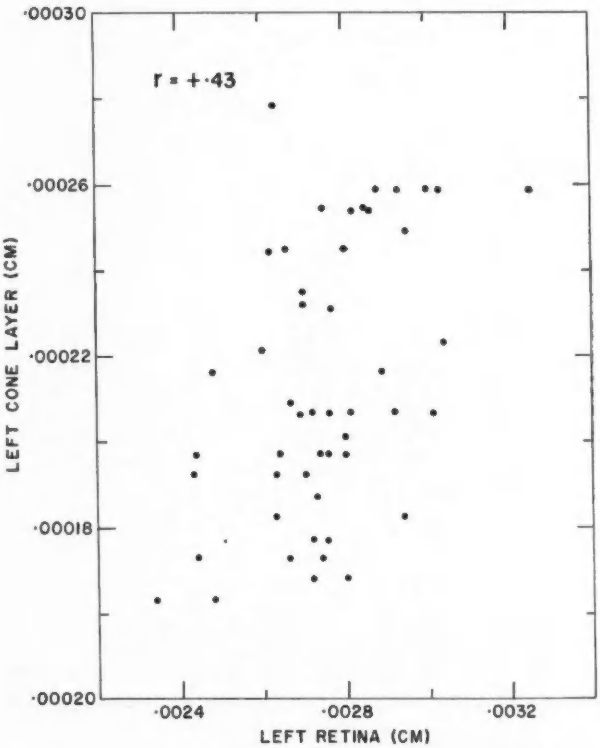

FIG. 2. Thickness of cone layer plotted against thickness of retina, for the left eye.

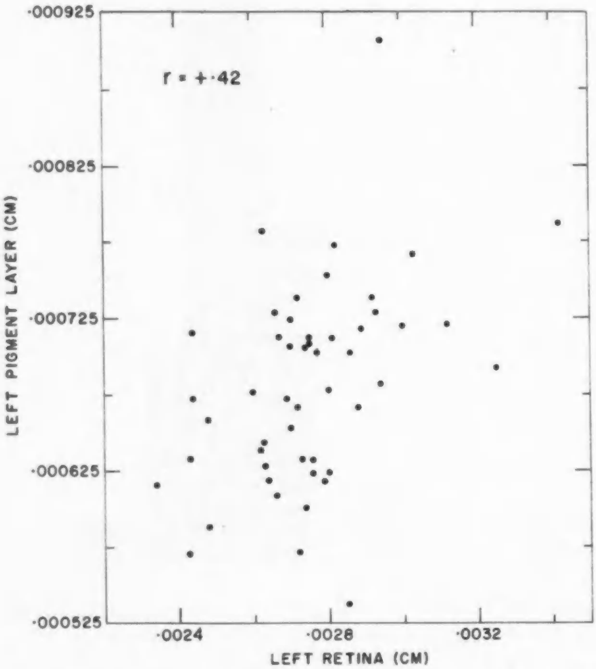

FIG. 3. Thickness of pigment layer plotted against thickness of retina, for the left eye.

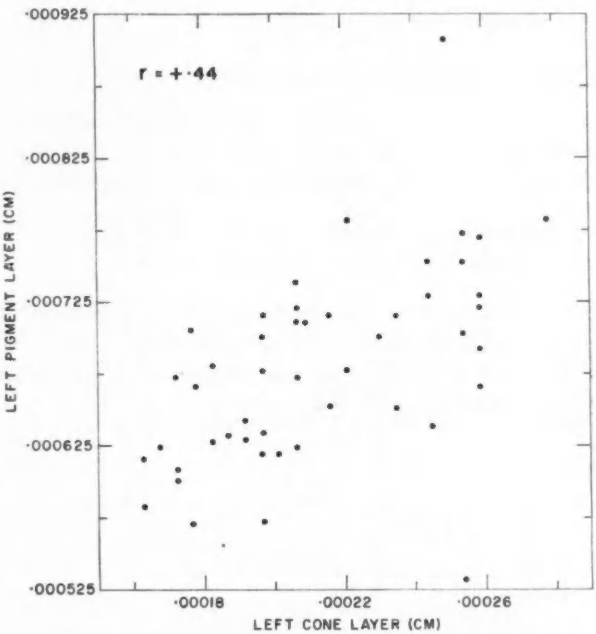

FIG. 4. Thickness of pigment layer plotted against thickness of cone layer, for the left eye.

Comparisons of Intra-ocular With External Characters (Fig. 5–7)

If the correlations among intra-ocular measurements are not large, then the correlations between intra-ocular and the highly-correlated external morphological measurements cannot be expected to be large either, which is in fact the situation (Table I). The coefficients of correlation between intra-ocular and morphological measurements are in fact somewhat smaller than those among the intra-ocular measurements, as seems natural.

Comparison of the Two Eyes of Each Fish (Fig. 8–11)

As a further step, the eye diameter and each of the intra-ocular measurements of the left eye of each fish was compared with the corresponding measurement from the right eye. The resulting correlation coefficients follows:

Measurement	Eye diameter	Retina	Cone layer	Pigment layer
Coefficient	+0.82	–0.03	+0.39	+0.29

Only the external measurement, eye diameter, shows a large correlation between left and right eyes. Therefore, while for each fish the size of the two eyes tends to be about equal, this is not so, or at most weakly so, for the thickness of the retinal, cone and pigment layers in the two eyes.

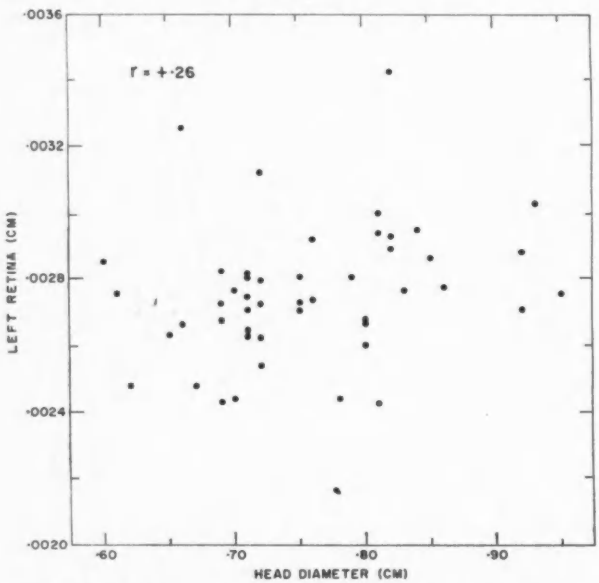

Fig. 5. Thickness of left retina plotted against head diameter.

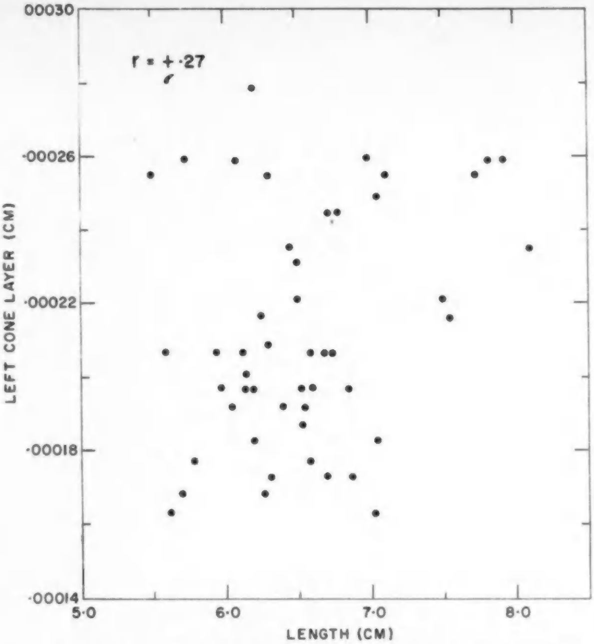

FIG. 6. Thickness of cone layer of the left eye plotted against body length.

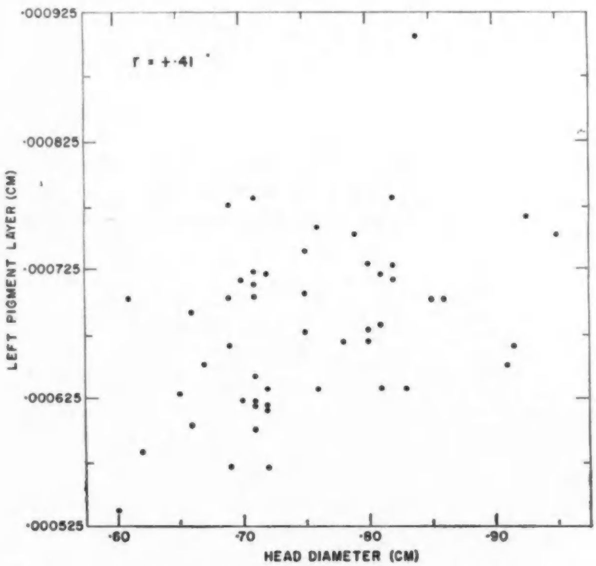

FIG. 7. Thickness of pigment layer of the left eye plotted against head diameter.

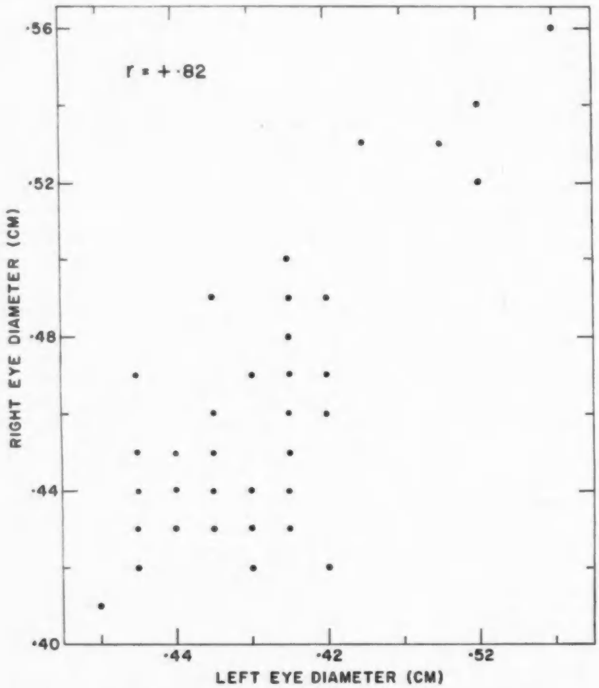

FIG. 8. Right eye diameter plotted against left eye diameter.

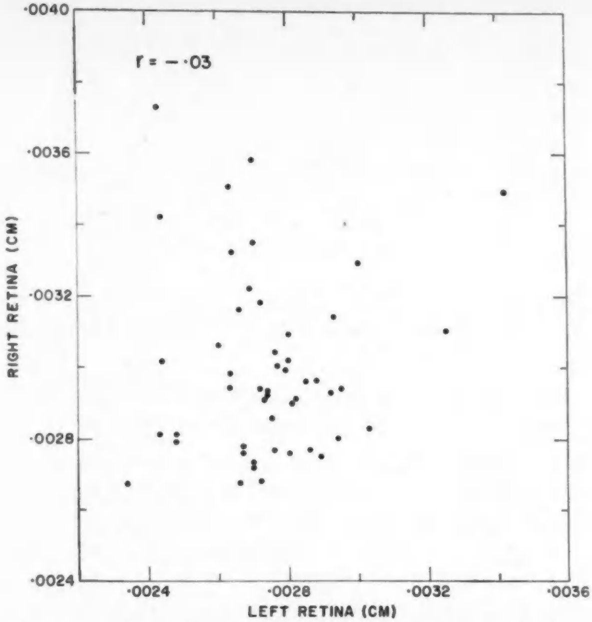

FIG. 9. Thickness of retina of the right eye plotted against thickness of retina of the left eye.

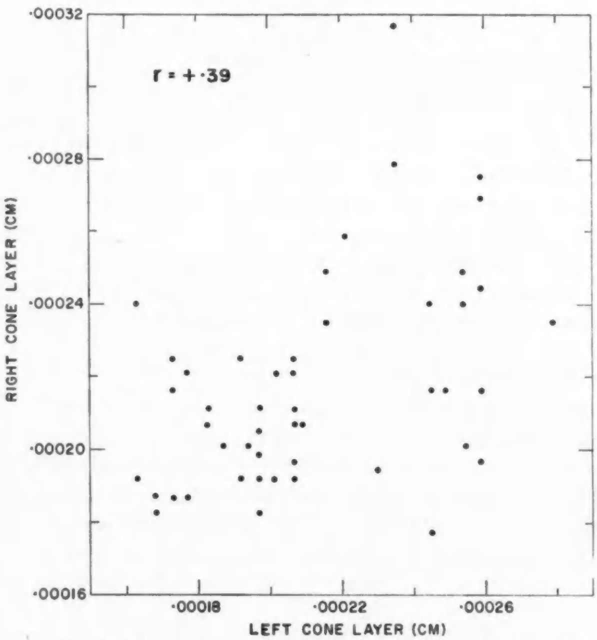

FIG. 10. Thickness of cone layer from the right eye plotted against thickness of cone layer from the left eye.

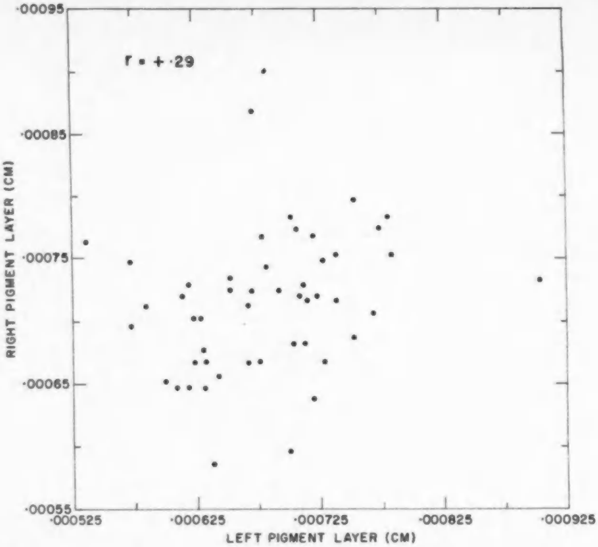

FIG. 11. Thickness of pigment layer of the right eye plotted against thickness of pigment layer from the left eye.

DISCUSSION

There is a possibility that the results above may have been influenced, to a minor extent, by the histological technique. It is conceivable that not all eye sections were cut on exactly the same plane. The eye is circular, and during embedding in the paraffin one may have been oriented in one way and another somewhat differently. Besides, although every attempt was made to make the microscopic measurements from the sections of the eye taken from the centre (viz. the exact middle dividing line), it is possible that not all sections measured were from exactly the same region. This makes for a margin of inaccuracy in the intra-ocular measurements, which undoubtedly exceeds that of the morphological measurements. However, the possible variability from this source seems small, quite inadequate to account for the marked absence of useful correlation among the intra-ocular measurements.

Since technical variability can be discounted, there remain two principal possibilities. 1. At the light intensity used the retina, cone layer and pigment layer may each be of more or less constant thickness within each eye, each congenitally determined and changing slowly if at all; the thickness of each of these layers being largely independent of the other layers within the same eye, independent of the thickness of the same layer in the eye of the other side of the fish, and independent of fish size. 2. Alternatively, we might imagine that

retina, cone layer and pigment layer vary continuously in thickness (within the numerical limits shown in our figures) over short time periods, of the order of hours or days; each eye and each layer varying independently of the other, independently of the (constant) general external illumination, and independently of the general physiological condition of the fish (changes in which reach the two eyes equally).

SUMMARY

1. Length, cube root of weight, head diameter, and eye diameter show large correlations (+0.82 or more) among themselves, in Atlantic salmon yearlings of 55–80 mm fork length.
2. Coefficients of conditions ($100W \div L^3$) range from 0.40 to 1.0 with all but four cases falling in the 0.50 to 0.70 range.
3. Intra-ocular measurements made by histological methods, viz. thicknesses of retina, cone layer and pigment layer, show poor coefficients of correlation (0.42–0.44) among themselves, and even smaller correlations with any of the external morphological measurements.
4. The results suggest that at a given moment the internal ocular structure is peculiar to each eye of each fish, and is practically independent of fish size over the range examined.

ACKNOWLEDGMENTS

Our thanks are due to Mr J. M. Butler and Mr A. J. Baxter of the Fish Culture Branch of the Canada Department of Fisheries for kindly supplying the fish used in this investigation. The assistance of Miss Judith Press and Mr D. Mercer with histology and statistical treatment of the data is gratefully acknowledged.

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A Note on the Morphology of the Basins of the Great Lakes[1]

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ABSTRACT

Neumann (1959) has suggested the elliptic sinusoid as a model for an average lake. Area–depth curves for the Great Lakes are compared with the corresponding curves given by the Neumann model which, it is suggested, should be useful in idealized calculations on a lake.

THE PRESENCE of the Great Lakes as a closely connected series of large basins must first be thought as requiring unusual explanation. However the relief of the basins is only about 1 in 3000, and Hough (1958) has concluded that differential glacial scouring of preglacial drainage channels in relatively soft sedimentary rocks (added possibly, in the cases of Lake Michigan and Lake Huron, to ancient collapse of salt domes) provides a reasonable explanation of them. The 5 lakes in a series will then be considered as being due to the chance workings of glacial scour, and drainage, and to local peculiarities in eroded sedimentary forms rather than to more subtle results of basic precambrian structure.

The resulting peripheral shapes of each of the Great Lakes differ substantially, but the area–depth profiles shown in Fig. 1 have much the same form, save for Lake Erie which is much more shallow than the others, and Lake Superior which has a very irregular basin. These profiles were obtained from published charts of the Canadian Hydrographic Service and, for Lake Michigan, of the United States Lake Survey. The published soundings are presumed complete and accurate for all Lakes except for a central area of Georgian Bay and this gap was partially filled by soundings taken during surveys by R/V *Porte Dauphine* in 1959. The shorelines were arbitrarily restricted by exclusion of certain bays and inlets, so that other assessments might differ from these by a few per cent.

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Mr K. Haessler did the planimetric work with a planimeter kindly made available by Mr J. Murray, Conservation Branch, Ontario Department of Planning and Development.

The profiles are useful in volumetric calculations such as the determination of total heat content from bathythermographic surveys.

An interesting comparison of the average depth ($\overline{D}$) and maximum depth (D_m) of over one hundred lakes by Neumann (1959) showed that the mean ratio

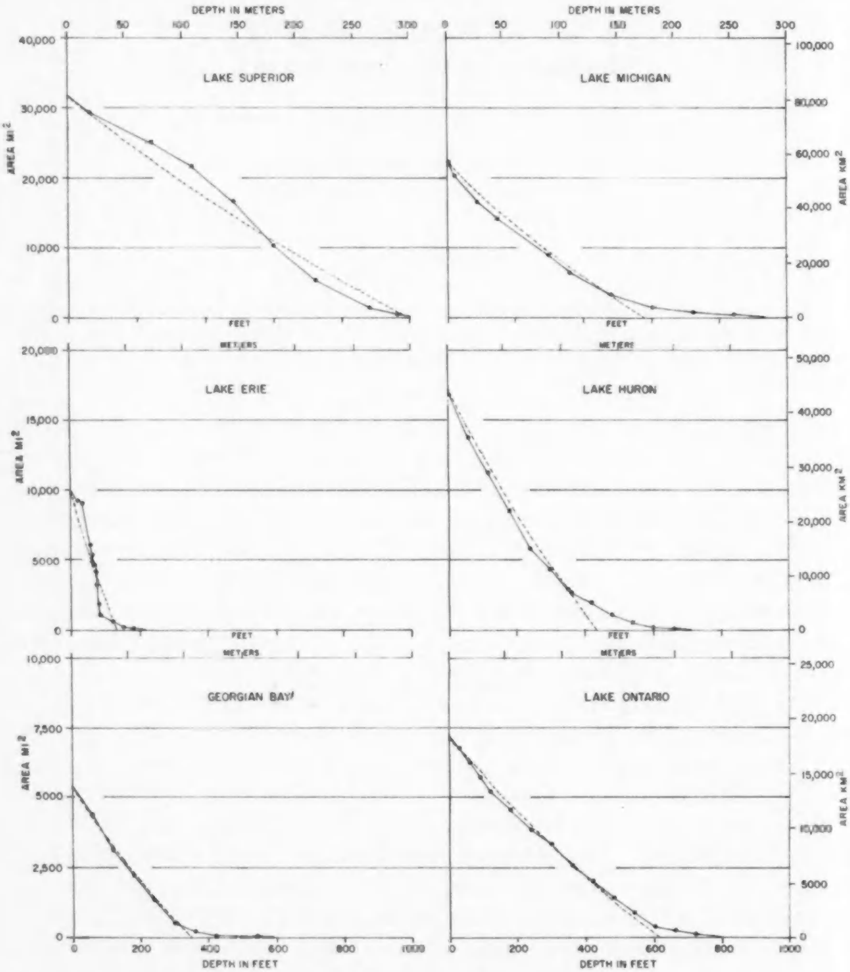

FIG. 1. Area versus depth: solid line, areas determined from hydrographic charts; dotted line, areas by Neumann's model.

of the two, as observed in nature, is 0.467. He proposed that the best model of an average lake basin is an elliptic sinusoid, for which $\overline{D}/D_m = 0.463$. Neumann plotted (his fig. 1) D_m versus $\overline{D}$, but it seems better to plot as well the ratio $\overline{D}/D_m$ versus $\overline{D}$ to show the scatter as in Fig. 2. Table I gives the averages of the ratio for various size classes of lakes and the average deviations.

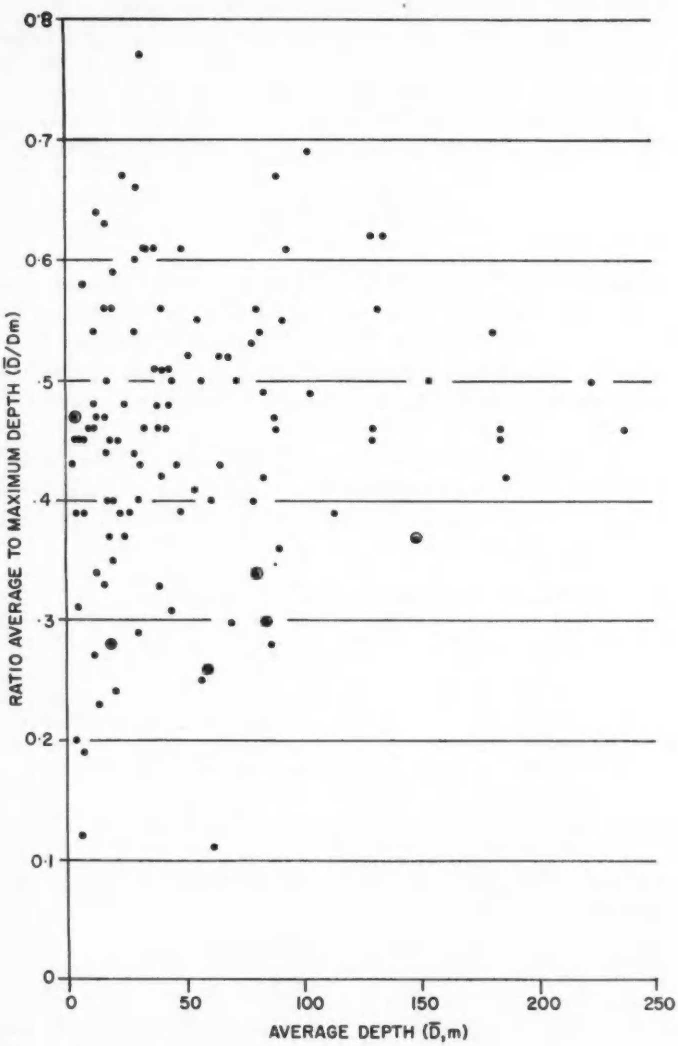

FIG. 2 Ratio of average depth and maximum depth versus average depth (values for the Great Lakes are accentuated); after Neumann (1959).

TABLE I

	Range of average depth, meters		
	0–50	50–100	100–200
Number in sample	71	26	14
Average $\overline{D}/D_m$	0.45	0.43	0.50
Average deviation	0.10	0.11	0.08

The choice of an elliptic sinusoid is not, therefore, critical but is a very convenient one, since the formulae associated with it are so simple (Neumann, p. 927). If the lake surface be approximated by an ellipse of semi-major and -minor axes, a and b, and the amplitude of the sinusoidal profiles is D_m, the volume V is:

$$V = 4\left(1-\frac{2}{\pi}\right)ab\ D_m \quad \ldots \quad (1)$$

and the surface area is $A = \pi ab$. This suggests that for purposes of comparison of maximum depth with other lakes, (1) be used to calculate an *effective* maximum depth $\overline{D}_m = 2.16\ \overline{D}$, the citation of $\overline{D}_m$ having much more significance, morphologically speaking, than the single measurement D_m. In the case of lakes with complicated bottom shapes, D_m is a single value with only very limited significance.

Table II gives the pertinent characteristic values for the Great Lakes. Fitting values of a and b is somewhat arbitrary of course. As noted above, the figures cited differ from those quoted by the United States Lake Survey and Canadian Hydrographic Service.

TABLE II. Hydrographic data for the Great Lakes

	Area	b	a	Vol.	D_m	$\overline{D}$	$\overline{D}_m$
	mi^2	mi	mi	mi^3	ft	ft	ft
Superior	31,700	50	202	2,796	1,302	464	1,000
Michigan	22,400	45	158	1,134	923	268	579
Georgian Bay	5,380	30	57	164	...	161	348
Huron	17,350	50	110	664	750	202	436
Erie	9,970	30	106	116	210	61	132
Ontario	7,250	25	92	390	778	284	615

It can be shown that the area of the level surface at depth z of the model lake corresponding to the actual lake is:

$$A_z = \frac{4ab}{\pi}\left(\cos^{-1}\frac{z}{\overline{D}_m}\right)^2 \quad \ldots \quad (2)$$

and the dotted curves in Fig. 1 give the figures calculated from (2) for each lake. The assumed elliptic sinusoid model is shown to be good for Michigan, Huron, Ontario and Georgian Bay but poor for Superior and Erie.

It appears that Neumann's model could be useful, especially because of its arithmetic simplicity, in idealized calculations in which preservation of volumetric change with depth is important.

ACKNOWLEDGMENT

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NOTES

Occurrence of Two Species of Juvenile Rockfish in Queen Charlotte Sound

On August 25, 1960, scientists aboard the *John N. Cobb* sighted and recovered a Japanese glass fishing float, 7½ miles NNW of Triangle Island in Queen Charlotte Sound (Lat. 50° 59.4′ N, Long. 129° 2.8′ W). The 12-inch (30-cm) diameter float was covered with ¼-inch (6-mm) cotton cord webbing. Attached to the webbing was a large mass (Fig. 1) of gooseneck barnacles (*Lepas anatifera*).

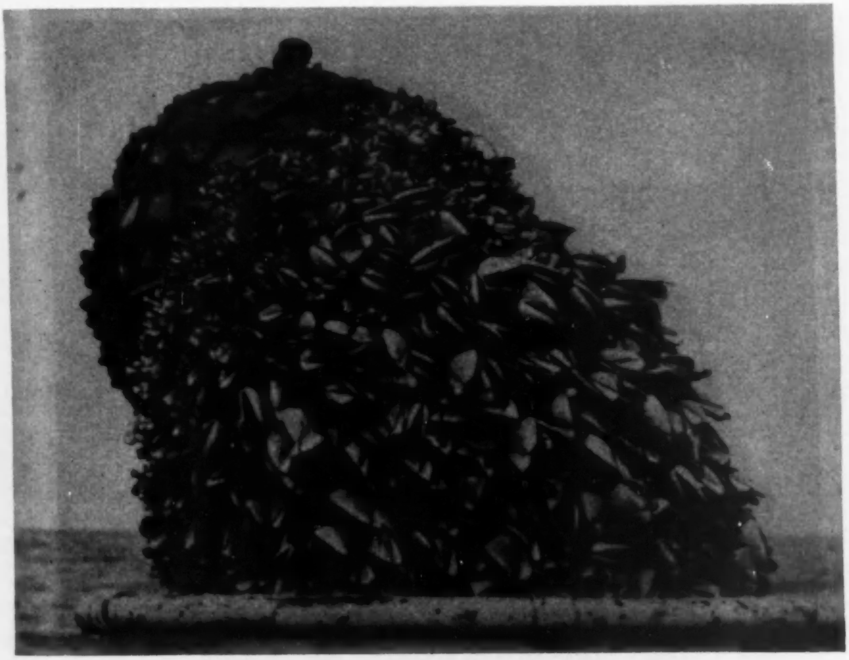

FIG. 1. Barnacle mass attached to the Japanese glass fishing float.

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Upon close observation of the barnacle mass 8 juvenile rockfish, all under 55 mm in length, were discovered. The young rockfish had apparently adopted the mass of barnacles for cover or feeding.

Information on the distribution and habitat of juvenile rockfish (*Sebastodes*) off the North American coast is rather fragmentary. Partlo (1950) reports that young rockfish, tentatively identified as *Sebastodes pinniger*, constitute one of the main food items of albacore taken off British Columbia, and Powell *et al.* (1952) report that juvenile *Sebastodes alutus* and *S. crameri* constitute major food items for albacore taken off the Washington and Oregon coasts.

The 8 rockfish found among the barnacles could be divided into two groups by their general appearance. Four of the rockfish had distinct black bands over a yellowish-gold background. The others were of a brownish-red colour with no distinct markings (Fig. 2). Meristic and morphometric data for the specimens are given in Table I, and were compared with those given by Phillips (1957). Specimens having black stripes were identified as *Sebastodes nigrocinctus* and those having a brownish-red colour appeared to be *Sebastodes caurinus*.

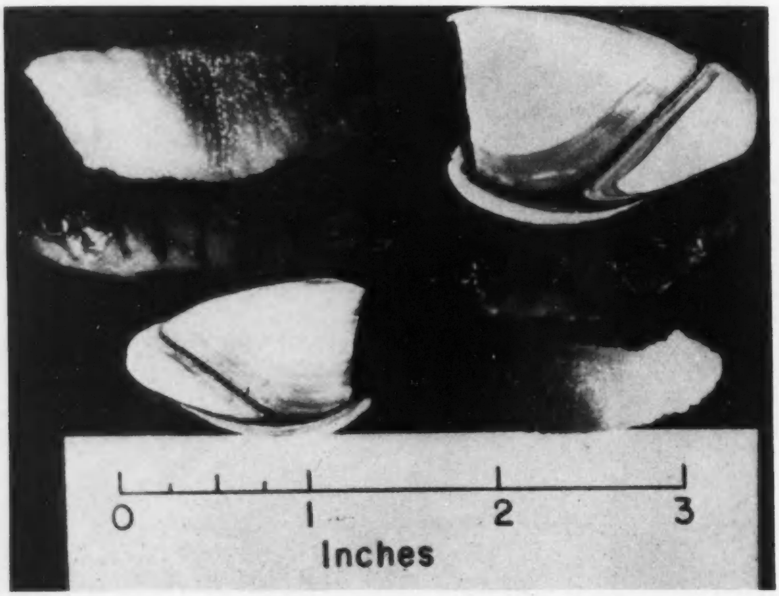

FIG. 2. Two species of juvenile rockfish with representative specimens of the gooseneck barnacle. Left—*Sebastodes nigrocinctus*; right—*S. crameri*.

TABLE I. Meristic and morphometric data of 8 rockfish specimens taken from the barnacle mass.

	Individuals with black bands				Individuals without black bands			
	1	2	3	4	1	2	3	4
Total length, mm	47	47	45	40	52	45	42	43
Standard length, mm	40	39	38	33	42.5	38	36	36
Head length, mm	15	15	14	13	17	14.5	13.5	12.5
Head length into st. length	2.66	2.60	2.71	2.54	2.5	2.62	2.67	2.88
Gill raker count	30,29	26,–	28,28	27,26	30,29	28,29	27,28	28,28
Lateral line pores	49,48	49,46	47,45	49,47	41,38	43,44	44,40	40,41
Head Spines *Absent*	Supraocular—on 2 individuals the nuchial also could not be distinguished.				Supraocular, coronal, nuchial.			

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PHILLIPS, J. B. 1957. A review of the rockfishes of California. *California Dept. Fish and Game, Fish Bull.*, No. 104.

Abnormalities in Lake Erie Whitefish

During an investigation of the Lake Erie commercial whitefish (*Coregonus clupeaformis*) catch in the years 1947 to 1949, notes were made on the morphological appearance of each fish handled. Visible abnormalities were noted in 11% of 1709 whitefish examined. Most of the fish examined belonged to the 1944 year-class. In 1956, Dr R. G. Ferguson, Division of Research, Ontario Department of Lands and Forests, at the writer's request, examined a sample of 108 Lake Erie whitefish and found 10% had abnormal caudal fins. By contrast, no visible skeletal abnormalities were recorded from over 10,000 whitefish examined between 1950 and 1960 from Heming Lake, Manitoba, situated at Lat. 54° 30′ N.

The most common abnormality, found in 9% of the sample, was that the dorsal lobe of the caudal fin was considerably shorter than the ventral lobe. Intergrades between abnormal and normal fins may have existed, but only obvious differences were recorded. Apparently the upper portion of the hypural plate was considerably thickened, tending to shorten the rays of the dorsal lobes of the fin.

The caudal fin appeared lunate rather than forked in 1% of the sample.

Extreme humpbackedness was noted in 0.5% of the sample.

The most striking but least frequent deformities (less than 0.5%) are shown at the top and bottom of Fig. 1. The vertebral columns of these fish are reduced in length by the fusion of adjacent centra. In both fish at least 17 vertebrae are compacted. The neural and haemal processes appear to be present in normal numbers. The whitefish shown in the middle of the photograph exhibits two compacted vertebrae in the mid-region. Such minor anomalies are not recognizable from external inspection and would escape detection, so it is quite probable that more than 11% of the sample had skeletal abnormalities of some type.

Skeletal anomalies are not rare among freshwater fishes, as Scott (1951) found that 5.4% of Lake Erie ciscoes (*Leucichthys artedi*) had vertebral deformities, and Gosline (1947) considered 5.8% of 1058 *Poecilichthys exilis* to be deformed. Extremely asymmetrical tails (similar to those described above) were noted by Stone (1938) among the ciscoes (*L. artedi*) of the deep-bodied type in Irondequoit Bay, Lake Ontario.

McHugh and Barraclough (1951) described an abnormality in carp and pointed out that fusions and deformities involving limited numbers of vertebrae are not uncommon in natural populations and most commonly occur at the posterior end of the vertebral column. O'Donnell (1945) described an abnormal carp in which the last 8 precaudal and 17 caudal vertebrae were completely fused and concluded that the condition resembled *arthritis deformans* as found in man and other mammals.

How such anomalies arise is not clearly understood. Alderdice *et al.* (1958) reported that in early developmental stages of chum salmon eggs an oxygen level of 0.4 ppm or less, although not lethal, resulted in the production of monstrosities. Price (1940) showed that the most favourable temperature for the embryonic

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development of whitefish was 0.5°C (33°F) and that abnormalities are produced if the developmental temperatures are 6°C (42.8°F) or over. The high frequency of abnormalities in Lake Erie whitefish, and their apparent absence in Heming Lake whitefish, is probably to be accounted for by differences in developmental conditions. The most obvious difference, considering the geographical location of these habitats, might be water temperature during the spawning and incubation period. At Heming Lake the peak of spawning occurs during the latter part of October at about 6°C (43°F). The water temperature rapidly decreases to 0.5°C (33°F), the optimum for development, and remains at that temperature until about the first week in May. The developing eggs are subjected to a relatively constant temperature during embryonic development. In Lake Erie the water temperature decreases later in the season, but the peak of spawning occurs when the temperature is about 6°C (43°F), as in Heming Lake. During the spawning period, however, marked fluctuations in water temperature often occur before the temperature reaches the optimum for development, and the incubation period is probably considerably shorter than at Heming Lake. The high incidence of abnormalities in Lake Erie, as indicated in samples taken in 1948–1949 and again in 1956, may result from unfavourable water temperatures during embryonic development.

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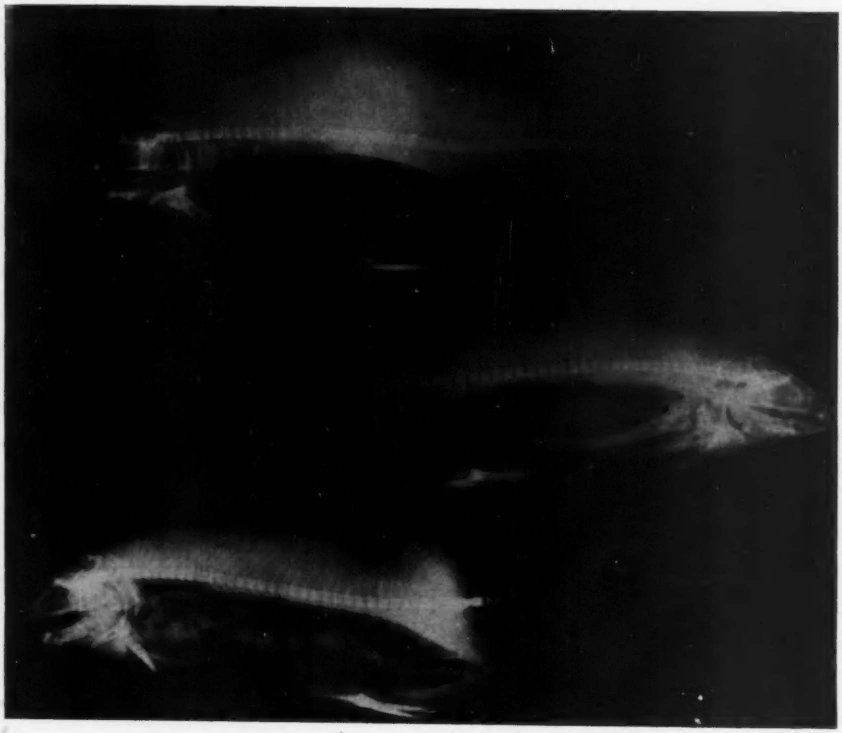

FIG. 1. X-ray photograph of abnormal vertebrae of Lake Erie whitefish.

Biosynthesis of Trimethylammonium Compounds in Aquatic Animals. II. Role of Betaine in the Formation of Trimethylamine Oxide by Lobster (*Homarus americanus*)

The utilization by the American lobster of choline-methyl-C^{14} for the formation of trimethylamine oxide has been described in a previous communication (Bilinski, 1960). Because the oxidation of choline to betaine was also observed, the possibility that this transformation is an intermediate step in the biosynthesis of trimethylamine oxide has been considered. To complete the previous series of experiments, the role of betaine in the formation of trimethylamine oxide has been investigated in lobsters and the present note reports a brief study on the incorporation *in vivo* of radioactive carbon from betaine-methyl-C^{14} into trimethylamine oxide.

Betaine-methyl-C^{14} hydrochloride was prepared from methyl-C^{14} iodide and unlabelled glycine by following the procedure of du Vigneaud *et al.* (1946). Methyl-C^{14} iodide was purchased from Nuclear Chicago Corp. The decomposition of betaine reineckate was, however, not carried out with Ag_2O, as described in the method of du Vigneaud *et al.* The use of a cation exchange resin for conversion of choline reineckate to choline chloride was described recently by Arnstein (1960) and in the present work essentially his procedure was employed for the conversion of betaine reineckate to betaine hydrochloride.

The methods used for the administration of labelled compounds, isolation of trimethylamine oxide and betaine, and determination of the specific radioactivity were described previously (Bilinski, 1960).

Data on the administration of betaine to lobsters and the experimental results are presented in Table I. As indicated in this Table, after administration of betaine-methyl-C^{14} only trace amounts of radioactivity are found in trimethylamine oxide, which has a specific activity 100 to 200 times lower than betaine isolated from lobsters at the end of the two metabolic periods. On the other hand it was found previously (Bilinski, 1960) that after administration of choline-methyl-C^{14} to lobsters the specific activity of trimethylamine oxide amounted

TABLE I. Utilization of betaine-methyl-C^{14} hydrochloride for biosynthesis of trimethylamine oxide in lobsters.

Expt. No.	Weight of lobsters	Metabolic period	Amount administered per 100 g body weight	Specific radioactivity (counts per minute[a])		
				Betaine		Trimethylamine oxide isolated from lobsters
				Administered to lobsters	Isolated from lobsters	
	grams	*hours*	*µM*			
1	495	18	2.65	78,000[b]	1950	<10
2	453	42	2.65	78,000[b]	750	<10

[a]Per infinitely thick planchet (3.8 sq cm) of $BaCO_3$.
[b]For measurement of radioactivity labelled betaine was diluted with a known amount of unlabelled betaine.

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to over half of that of betaine. These figures provide no support for the possibility that the oxidation of choline to betaine is an intermediate step in the formation of trimethylamine oxide from choline in lobster.

In connection with this study it might be noted that it has been observed with bacteria that species which produce trimethylamine from choline and acetylcholine have not the ability to convert betaine to trimethylamine (Dyer and Wood, 1947; Campbell and Williams, 1951; Eddy, 1953). Similarly, an enzyme preparation from the leaves of *Chenopodium vulvaria* has been shown to cause the breakdown of choline with liberation of trimethylamine, but not to yield trimethylamine from betaine (Cromwell, 1950). A recent study by Baker and Chaykin (1960) on liver homogenates and subcellular fractions presents further evidence for the presence in animals of an enzyme system capable of oxidizing trimethylamine to trimethylamine oxide.

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Decay of Hexachlorocyclohexane in Sea Water

Hexachlorocyclohexane (HCH), more popularly known as benzene hexachloride, has received considerable attention in recent years as an insecticide. It has found effective application in the control of the ambrosia beetle, which attacks fallen logs in the forest and logs on booming grounds. In a study of some of the effects of this insecticide on freshwater and marine fishes, chemical research was instigated to explore its behaviour in sea water.

The instability of the various isomers of HCH to alkali has been described (Slade, 1945). Alkaline dehalogenation of the α and γ isomers in various solvents including water has been reported (Daviaud and Viel, 1952). The reaction under the influence of hot, concentrated, alcoholic alkali is known in detail (Cristol, 1947).

Occurrence of substitution reactions in cold, dilute, weakly alkaline solutions was investigated by several workers and summarized by Ingold (1953, p. 464). Essentially such conditions prevail in the sea and hence a gradual decay of the HCH isomers can be expected. Experiments were conducted to determine the decay rate.

In view of the low solubility of the isomers (Ivanov, 1956), particular care had to be exercised to prepare homogeneous reaction mixtures. A combination of predissolving the substances in diethyl ether, prolonged shaking, filtering, and further diluting proved successful toward this end.

The reaction was allowed to take place at room temperature (*ca.* 20°C) in (a) polyethylene and (b) pyrex glass bottles. The use of polyethylene containers resulted in a more rapid decrease of the apparent HCH concentrations. This may have been caused by adsorption on the polyethylene surface.

The analyses were done by a modification of the method of Hancock and Laws (1955), which is claimed by them to be insensitive to interference by volatile aromatic (presumably also alicyclic) compounds. Its applicability to sea water was tested and confirmed.

Experiments were conducted to test for interference by compounds belonging to groups which could possibly appear as intermediate or end products of the action of sea water on γ-HCH. With several of the compounds a negative test was obtained (Table I).

The α, β and γ isomers are usually all present in commercial HCH-containing insecticides, and if these mixtures are exposed to sea water a differential decay may be expected. Differences in decay rates are shown by the curves presented in Fig. 1. These agree with the reactivity differences observed polarographically (Schwabe, 1953).

Experiments with Millipore-filtered (i.e., nearly sterile) and unfiltered sea water indicate that the reaction is a chemical one and not dependent on the presence of marine organisms.

A comparison of the decay curves for γ-HCH in 50% sea water + 50% distilled water, and in pure sea water, shows that the reaction rate is higher in the latter.

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TABLE I. Effect of various compounds on the Hancock and Laws test for hexachlorocyclohexane (HCH).

Group	Compounds tested	Result
Alicyclic		
chlorides	*Trans*-1,2-dichlorocyclohexane	Positive (brownish colour)
chlorocyclanols	*Trans*-2-chlorocyclohexanol	Positive (brownish colour)
cyclanols	Cyclohexanol	Negative
cyclitols	*Meso*-inositol	Negative
Aromatic		
chlorides	1,2-Dichlorobenzene	Positive (brownish colour)
	1,2,4-Trichlorobenzene	Positive (brownish colour)
chlorophenols	*o*-Chlorophenol	Positive (brownish colour)
phenols	Phenol	Negative
	Pyrogallol	Negative

This is as expected inasmuch as the reaction apparently depends on the hydroxyl-ion concentration of the solvent.

Other studies have shown in a week-old reaction mixture the absence of *trans*-1,2-dichlorocyclohexane, *trans*-2-chlorocyclohexanol and the di- tri- and tetra-chlorobenzenes. It remains a question as to what the reaction products are and if they give a positive reaction when subjected to Hancock and Laws'

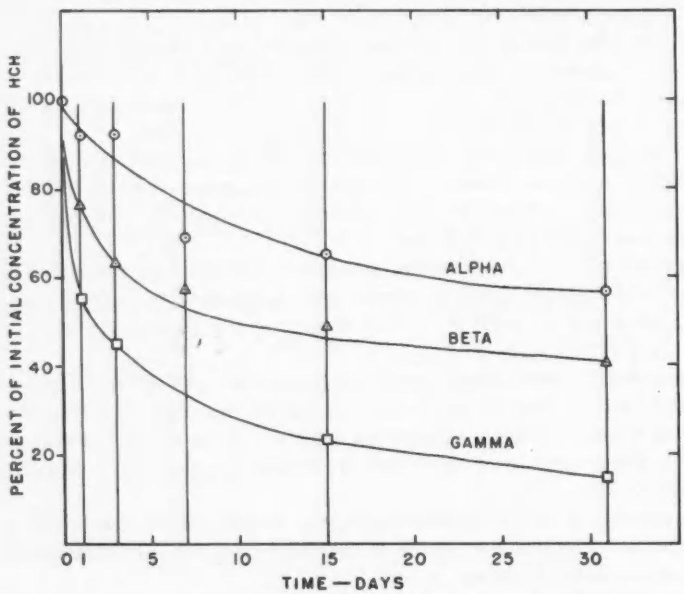

FIG. 1. Decay of isomers of hexachlorocyclohexane (HCH) in sea water. (Polyethylene bottles; coastal sea water.)

procedure. Samples of the reaction mixture showed that even after 12 months of storage (at 20°C) a relatively high apparent γ-HCH concentration remained. It is not possible at present to decide if this is a consequence of stable end products or residual γ-HCH.

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A New Record of the Long-finned Cod, *Antimora rostrata* Gunther, from British Columbia Waters

On August 17, 1960, a rare specimen of the long-finned cod (*Antimora rostrata* Gunther) was caught by Mr M. Hestnes, skipper of the long-liner *Sentinella*, while fishing in waters off the west coast of Vancouver Island. The place of capture was approximately 15 miles southwest of Kyuquot Sound (49°49′N, 127°41′W) and the depth was 250 fathoms.

This is the fourth record from waters adjacent to the British Columbia coast. The three previous specimens were obtained by the *Albatross* expeditions of 1888 and 1890 at Stations 2860 (two) and 3342 (one), respectively, both in the vicinity of the Queen Charlotte Islands (Clemens and Wilby, 1946: 133–134). These early records were obtained from very deep water (876 fathoms and 1588 fathoms, respectively). Likewise, other specimens from other regions of the North Pacific and Atlantic Oceans have been taken in very deep water. The present record is, therefore, somewhat unique in respect to depth of capture.

According to Clemens and Wilby, specimens from the northeastern Pacific Ocean were originally described by T. H. Bean in 1890 as *Antimora microlepis*, a name subsequently considered by Schroeder (1940) to be synonymous with *A. rostrata* Gunther of the Atlantic Ocean. In his monograph of the gadoid fishes of the USSR, Svetovidov (1948: 69) retains the name *A. microlepis* Bean to distinguish the long-finned cod of the North Pacific Ocean.

The present specimen, measuring 38.5 cm in total length, has been deposited in the museum of the Institute of Fisheries at the University of British Columbia.

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Egg Counts of Lake Erie Whitefish

Very little information on the egg numbers of Lake Erie whitefish (*Coregonus clupeaformis*) has been published. The following scanty data may help to fill some of the gaps in the existing knowledge.

During the last week of July and the first week of August, 1948, ovaries of 15 whitefish were removed and preserved in formalin. Total counts were not made but representative samples were taken from several parts of each ovary. These were weighed and the number of eggs in these samples was then counted. The total number was estimated from the ratio of the weight of the eggs sampled to the total weight of the ovary. Connective tissue and blood vessels were removed to minimize extraneous weight that would influence the total count.

Fourteen of the 15 specimens belonged to the 1944 year-class which was so abundant in the commercial catch at that time. The other whitefish belonged to the 1940 year-class.

The counts obtained are shown in Table I.

TABLE I. Egg counts of Lake Erie whitefish captured in 1948.

Year class	Fork length	Weight	Calculated eggs per female
	mm	*g*	*no.*
1944	416	...	32,169
"	421	...	40,625
"	424	...	50,050
"	425	...	46,600
"	431	1,205	42,850
"	433	...	40,151
"	439	1,396	41,750
"	444	1,353	51,800
"	449	1,290	40,315
"	453	...	31,105
"	455	1,835	59,500
"	465	1,559	52,450
"	475	1,573	58,200
"	477	1,636	59,906
1940	551	2,891	121,700

The average number of eggs in whitefish of the 1944 year-class was 47,000, while the 8-year-old whitefish had over 100,000 eggs.

With few irregularities, it is apparent that a general relationship exists between size of fish and egg number, i.e., small fish produce fewer eggs than large fish.

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Egg diameters were obtained by placing 10 preserved eggs on a millimetre rule and taking the average. The average egg diameter of 13 whitefish ranged from 0.95 mm to 1.40 mm.

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